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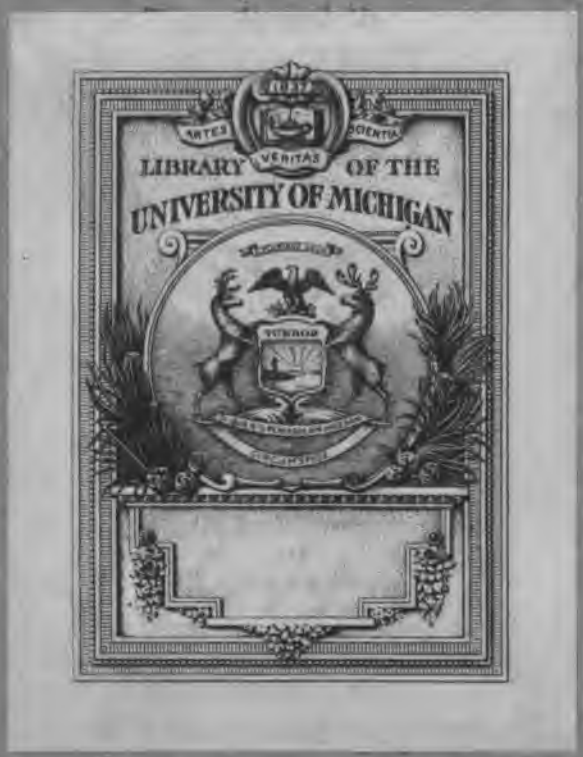

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PRESIDENT 1910
OF
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

TRANSACTIONS

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THE AMERICAN SOCIETY OF
MECHANICAL ENGINEERS

TRANSACTIONS

VOLUME 32

ATLANTIC CITY MEETING
MEETING IN ENGLAND
NEW YORK MEETING
1910

NEW YORK
PUBLISHED BY THE SOCIETY
29 WEST 39TH STREET
1911

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THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

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1910

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232749

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E .D. Leavitt	1883	Cambridge, Mass.
John E. Sweet	1884	Syracuse, N. Y.
J. F. Holloway	1885	Died September 1, 1896
Coleman Sellers	1886	Died December 28. 1907
George H. Babcock	1887	Died December 16, 1893
Horace See	1888	Died December 14, 1909
Henry R. Towne	1889	New York, N. Y.
Oberlin Smith	1890	Bridgeton, N. J.
Robert W. Hunt	1891	Chicago, Ill.
Charles H. Loring	1892	Died February 5, 1907
Eckley B. Coxe	1892–1894	Died May 13, 1895
E. F. C. Davis	1895	Died August 6, 1895
Charles E. Billings	1895	Hartford, Conn.
John Fritz	1896	Bethlehem, Pa.
Worcester R. Warner	1897	Cleveland, O.
Charles Wallace Hunt	1898	New York, N. Y.
George W. Melville	1899	Philadelphia, Pa.
Charles H. Morgan	1900	Worcester, Mass.
S. T. Wellman	1901	Cleveland, O.
Edwin Reynolds	1902	Died February 19, 1909
James M. Dodge	1903	Philadelphia, Pa.
Ambrose Swasey	1904	Cleveland, O.

PAST PRESIDENTS AND HONORARY COUNCILORS

1910

John R. Freeman	1905	Providence, R. I.
F. W. Taylor	1906	Philadelphia, Pa.
F. R. Hutton	1907	New York, N. Y.
M. L. Holman	1908	St. Louis, Mo.
Jesse M. Smith	1909	New York, N. Y.

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Meetings of the Society in New York

WALTER RAUTENSTRAUCH, *Chairman* — F. H. COLVIN
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Meetings of the Society in San Francisco

A. M. HUNT, *Chairman* — T. W. RANSOM, *Secretary*
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SPECIAL COMMITTEES

1910

On a Standard Tonnage Basis for Refrigeration

D. S. Jacobus — G. T. Voorhees
A. P. Trautwein — Philip De C. Ball
E. F. Miller

On Society History

John E. Sweet — H. H. Suplee
Chas. Wallace Hunt

On Constitution and By-Laws

Chas. Wallace Hunt, *Chairman* — F. R. Hutton
G. M. Basford — D. S. Jacobus
Jesse M. Smith

On Conservation of Natural Resources

Geo. F. Swain, *Chairman* — L. D. Burlingame
Charles Whiting Baker — M. L. Holman
Calvin W. Rice

On Identification of Power House Piping

H. G. Stott, *Chairman* — I. E. Moultrop
W. H. Bryan — H. P. Norton
J. T. Whittlesey

On International Standards for Pipe Threads

E. M. Herr, *Chairman* — Geo. M. Bond
William J. Baldwin — Stanley G. Flagg, Jr.

On Standards for Involute Gears

Wilfred Lewis, *Chairman* — E. R. Fellows
Hugo Bilgram — C. R. Gabriel
Gaetano Lanza

On Power Tests

D. S. Jacobus, *Chairman* — L. P. Breckenridge — Edward F. Miller
Edward T. Adams — William Kent — Arthur West
George H. Barrus — Charles E. Lucke — Albert C. Wood

On Standardization of Flanges

A. M. Mattice — J. P. Sparrow
Wm. Schwanhausser — H. G. Stott

On Student Branches

F. R. Hutton, Honorary Secretary

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1910

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INSTITUTION	BRANCH AUTHORIZED BY COUNCIL	HONORARY CHAIRMAN	PRESIDENT	CORRESPONDING SECRETARY
	1908			
Stevens Inst. of Tech., Hoboken, N. J.	December 4	Alex. C. Humphreys	W. G. H. Brehmer	J. G. Bainbridge
Cornell University, Ithaca, N. Y.	December 4	R. C. Carpenter	C. C. Allen	D. S. Wegg, Jr.
	1909			
Armour Inst. of Tech., Chicago, Ill.	March 9	G. F. Gebhardt	F. E. Wernick	W. E. Thomas
Leland Stanford, Jr. University, Palo Alto, Cal.	March 9	W. F. Durand	J. B. Bubb	H. H. Blee
Polytechnic Institute, Brooklyn, N. Y.	March 9	W. D. Ennis	A. L. Palmer	R. C. Ennis
State Agri. College, Corvallis, Ore.	March 9	Thos. M. Gardner	C. L. Knopf	S. H. Graf
Purdue University, Lafayette, Ind.	March 9	L. V. Ludy	H. A. Houston	J. W. Barr
University of Kansas, Lawrence, Kan.	March 9	P. F. Walker	W. F. Judy	M. C. Conley
New York Univ., New York	November 9	C. E. Houghton	Harry Anderson	Andrew Hamilton
Univ. of Illinois, Urbana, Ill.	November 9	W. F. M. Goss	B. L. Keown	C. S. Huntington
Penna. State College, State College, Pa.	November 9	J. P. Jackson	W. E. Heibel	G. M. Forker
Columbia University, New York	November 9	Chas. E. Lucke	F. R. Davis	H. B. Jenkins
Mass. Inst. of Tech., Boston, Mass.	November 9	Gaetano Lansa	Morrill Mackenzie	Foster Russell
Univ. of Cincinnati, Cincinnati, O.	November 9	J. T. Faig	H. B. Cook	C. J. Malone
Univ. of Wisconsin, Madison, Wis.	November 9	C. C. Thomas	A. MacArthur	A. Wegner
Univ. of Missouri, Columbia, Mo.	December 7	H. Wade Hibbard	H. W. Price	Osmer Edgar
Univ. of Nebraska, Lincoln, Neb.	December 7	C. R. Richards	W. J. Wholenberg	W. H. Burleigh
	1910			
Univ. of Maine, Orono, Me.	February 8	Arthur C. Jewett	H. N. Danforth	A. H. Blaisdell
Univ. of Arkansas, Fayetteville, Ark.	April 12	B. N. Wilson	C. B. Boles	W. Q. Williams
Yale University, New Haven, Conn.	October 11			W. Roy Manny

SUMMARY OF MEMBERSHIP

December 31, 1910

United States

Alabama	17	Nebraska	5
Alaska	1	Nevada	2
Arizona	3	New Hampshire	14
Arkansas	4	New Jersey	207
California	84	New Mexico	3
Colorado	34	New York	1113
Connecticut	135	North Carolina	12
Delaware	18	North Dakota	1
District of Columbia	31	Ohio	274
Florida	3	Oklahoma	1
Georgia	17	Oregon	14
Hawaii	3	Pennsylvania	454
Idaho	1	Philippine Islands	1
Illinois	248	Porto Rico	4
Indiana	74	Rhode Island	70
Iowa	8	South Carolina	3
Kansas	12	Tennessee	13
Kentucky	6	Texas	24
Louisiana	26	Utah	7
Maine	17	Vermont	13
Maryland	34	Virginia	29
Massachusetts	369	Washington	18
Michigan	122	West Virginia	7
Minnesota	19	Wisconsin	101
Mississippi	2	Wyoming	1
Missouri	65		
Montana	9	Total	3753

Foreign Countries

Africa	13	India	4
Australia	8	Italy	1
Austria	1	Japan	7
Belgium	5	Mexico	14
Canada	49	New Zealand	1
Central America	6	Norway	1
China	3	Russia	4
Cuba	4	Scotland	3
England	46	South America	14
Finland	1	Sweden	5
France	9	Switzerland	4
Germany	14		
Holland	1		
Hungary	2	Total	220

SUMMARY OF MEMBERSHIP

By Residence

December 31, 1910

Membership in United States	3753
Membership in foreign countries	220
Present address unknown	5
Total membership	3978

By Grade

December 31, 1910

Honorary Members	15
Members	2660
Associates	390
Juniors	913
Total membership	3978

United States

Alabama	4	Nebraska	2
California	9	New Jersey	15
Connecticut	7	New York	154
Delaware	1	Ohio	31
District of Columbia	7	Oklahoma	1
Georgia	1	Oregon	2
Illinois	23	Pennsylvania	34
Indiana	10	Rhode Island	6
Kansas	3	Texas	1
Maine	2	Vermont	1
Maryland	1	Washington	1
Massachusetts	28	Wisconsin	20
Michigan	13		
Minnesota	6		
Missouri	6	Total	389

Foreign Countries

Belgium	1	South America	1
Canada	2	Switzerland	1
Germany	2		
Mexico	1	Total	8

GAS POWER SECTION

By Residence

Membership in United States	389
Membership in foreign countries	8
Address unknown	2
Total membership	399

By Grade

Members of the Society	253
Affiliates	146
Total	399

STUDENT BRANCHES

Armour Institute of Technology	21
Columbia University	41
Cornell University	119
Leland Stanford Jr. University	9
Massachusetts Institute of Technology	17
Pennsylvania State College	64
Polytechnic Institute of Brooklyn	22
Purdue University	22
Rensselaer Polytechnic Institute	18
Stevens Institute of Technology	58
University of Arkansas	2
University of Cincinnati	32
University of Illinois	62
University of Kansas	12
University of Maine	13
University of Missouri	14
University of Nebraska	15
University of Wisconsin	36
Yale University	40
Total	617

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MEETINGS JANUARY–JUNE

NEW YORK MEETING, JANUARY 11

A meeting of the Society held in New York on January 11 was devoted to a discussion on Lubrication. C. F. Mabery, Professor of Chemistry at the Case School of Applied Science, Cleveland, presented a paper on Lubrication and Lubricants, dealing largely with laboratory tests in the performance of which Dr. Mabery has been signally successful and from which he has deduced interesting results both with oils alone, and with oil and graphite and water and graphite.

Following Dr. Mabery's address, a paper by F. H. Sibley upon Efficiency Tests of Lubricating Oils, was read by Charles E. Lucke. The discussion was opened by P. H. Conradson, chief chemist of the Galena-Signal Oil Company, Franklin, Pa., who sought to show the extent to which laboratory practice might be expected to have a bearing on the performance of lubricants in actual practice and explained certain practical considerations that must be taken into account in the lubrication of different types of machinery. Others who contributed to the discussion were William M. Davis, Henry Souther, F. R. Low, D. S. Jacobus, C. A. Hague and George A. Orrok.

BOSTON MEETING, JANUARY 31

A meeting of the Society held in Boston on January 31 took the form of a dinner, given in honor of the presidents of The American Society of Mechanical Engineers, the Boston Society of Civil Engineers, and the Boston Section of the American Institute of Electrical Engineers, George Westinghouse, George B. Francis and L. B. Stillwell; also to John A. Bensel, president of the American Society of Civil Engineers, and other distinguished guests. While the attendance was mainly from Boston and vicinity, there was a large representa-

tion from New York and a considerable number from other cities. The meeting emphasized in an unmistakable way the cordial relations existing between the different branches of the profession and the earnest desire for coöperation.

Following the dinner, C. B. Edwards, chief engineer of the Fore River Shipbuilding Company, gave a talk, illustrated by lantern slides, on The Main and Auxiliary Machinery of the Battleship North Dakota. This is the new "Dreadnaught" of the U. S. Navy, turbine driven of 20,000 tons capacity. Photographs were thrown on the screen of the ship under trial, of the machinery after installation, and many detail drawings were shown of the arrangement of the boilers, machinery and piping.

After the presentation and discussion of a plan for erecting an engineering building and clubhouse in Boston, the principal speaker of the evening, George Westinghouse, was introduced.

Mr. Westinghouse dwelt especially on the necessity of combined influence and of the power which the engineering societies had to better conditions by showing, from their knowledge and experience, that unregulated competition and rivalry in business have made ideal practice in industrial engineering most difficult of realization. In illustration, he spoke of the electrical industry, in which with the single exception of uniform bases for incandescent lamps there were practically no standards. In consequence, many millions of dollars had been added to investment already made in installations of electrical machinery, through lack of standardization of motors and other important parts. By coöperation in the development of apparatus, by the use of the same designs and by the exchange of engineering and manufacturing particulars, he believed the very best of all kinds of electrical machinery could be evolved and that the products of the companies could be made interchangeable, not only to the advantage of the consumers but to the companies themselves. He advocated further the establishment of a bureau of standardization which should undertake the reform of such existing practice.

NEW YORK MEETING, FEBRUARY 8

At a meeting of the Society in New York on February 8, a bronze memorial tablet erected in the rooms of the Society to Robert Henry Thurston, its first President, was formally dedicated. An account of the meeting appears elsewhere in this volume of Transactions.

BOSTON MEETING, FEBRUARY 16

A meeting of the Society in coöperation with the Boston Section of the American Institute of Electrical Engineers and the Boston Society of Civil Engineers was held on February 16 in Boston. An informal dinner preceded the meeting. David B. Rushmore, Mem. Am.Soc.M.E., chairman of the Industrial Power Committee of the Institute, presided during the presentation of the following papers: The Applicability of Electrical Power to Industrial Establishments, by Dugald C. Jackson, Mem.Am.Soc.M.E.; Central Stations vs. Isolated Plants for Textile Mills, by Charles T. Main, Mem.Am.Soc. M.E.; The Supply of Electrical Power for Industrial Establishments from Central Stations, by R. S. Hale, Mem.Am.Soc.M.E.; Illumination for Industrial Plants, by G. H. Stickney; The Requirements for an Induction Motor From the User's Point of View, by Walter S. Nye. A discussion followed, principally upon the paper by Mr. Main. These papers were published in the Proceedings of the American Institute of Electrical Engineers, for February 1910.

NEW YORK MEETING, MARCH 8

At a meeting of the Society in New York on March 8, in which the American Institute of Electrical Engineers coöperated, a paper by H. G. Stott, Mem.Am.Soc.M.E., and R. J. S. Pigott, on tests on the 15,000-kw. steam-engine-turbine unit located in the 59th Street Station of the Interborough Rapid Transit Company of New York, was considered. After the presentation by Mr. Stott of the main facts regarding these tests and the installation of the low-pressure turbine on which the tests were made, Mr. Pigott gave an account of the methods used, illustrating his talk with lantern slides.

The paper was discussed by C. P. Steinmetz, Max Rotter, O. Junggren, E. D. Dreyfus, G. R. Parker, F. Samuelson, John W. Lieb, Jr., D. S. Jacobus, H. H. Barnes, M. B. Carroll, W. L. R. Emmett, Wm. Robinson, B. R. Shover and C. O. Mailloux.

BOSTON MEETING, MARCH 11

A meeting of the Society was held in Boston, March 11, in which the Boston Section of the American Institute of Electrical Engineers and the Boston Society of Civil Engineers coöperated. Magnus W. Alexander, Mem.Am.Soc.M.E., presented his

paper, on The Training of Men, a Necessary Part of a Modern Factory System, briefly outlining the educational policy of the General Electric Company at Lynn, Mass., where a systematic training is provided, suitable to all classes of people. This was discussed by Henry E. Rhoades, Chas. F. Park, R. H. Smith, Ira N. Hollis, Gardner C. Anthony, Peter Schwamb, Luther D. Burlingame, G. C. Ewing, S. Fred Smith, H. S. Knowlton, Edward F. Miller and Dickerson G. Baker.

ST. LOUIS MEETING, MARCH 12

At a meeting of the Society with the Engineers Club of St. Louis, on March 12, in St. Louis, Flywheels was made the subject of a topical discussion. C. H. Benjamin, Mem.Am.Soc.M.E., opened the discussion with a review of the recent developments in testing flywheels, with an account of the latest apparatus and testing pit for this purpose at Purdue University. He was followed by G. M. Peek, J. D. McPherson, H. A. Ferguson and H. Wade Hibbard. Jesse M. Smith, Past-President, E. D. Meier, Vice-President, and Calvin W. Rice, Secretary, represented the Council of the Society at the meeting. An informal dinner preceded the professional session.

ST. LOUIS MEETING, APRIL 9

A meeting of the Society was held in St. Louis, April 9, the St. Louis Section of the American Institute of Electrical Engineers and the Engineers Club of St. Louis coöperating. A symposium on the Electric Drive in the Machine Shop was presented, to which three papers were contributed by the Society: The Economy of the Electric Drive, by A. L. DeLeeuw, Mem.Am.Soc.M.E.; Economical Features of Electric Motor Applications, by Charles Robbins, Assoc. A.I.E.E., of the Westinghouse Electric and Manufacturing Company; Mechanical Features of Electric Driving, by John Riddell, Mem.Am.Soc.M.E. A paper, Selection and Methods of Application of Motors and Controllers, by Charles Fair, Mem.A.I.E.E., of the General Electric Company, was contributed by the American Institute of Electrical Engineers. The papers were discussed by M. L. Holman, W. F. M. Goss, E. R. Fish, A. H. Timmerman, P. A. Morse, H. H. Humphrey, O. Stephensen, A. S. Langsdorf, Wm. H. Bryan and H. Wade Hibbard.

NEW YORK MEETING, APRIL 12

A meeting of the Society in New York was held on April 12, the American Institute of Electrical Engineers coöperating. The subject was the Electric Drive in the Machine Shop, with the same four papers that were presented at the meeting in St. Louis. The economic side of the subject was very fully discussed by representatives of the machine tool industry and other users of motors as well as by the motor manufacturers. Fred. L. Eberhardt, Mem.Am.Soc.M.E., Vice-President of the National Machine Tool Builders Association, spoke officially for his organization of their efforts, with the American Association of Electric Motor Manufacturers, for the securing of standards for motor equipment. A. L. DeLeeuw, Mem.Am.Soc. M.E., a member of the committee of the National Machine Tool Builders Association to consider this subject, followed with a detailed account of the efforts at standardization to date, in which he said fifteen points had been raised for discussion and that seven of them had been considered by the joint committee thus far, among them being the subjects of horsepower, voltages, speeds and ratings.

The papers were also discussed by Henry Hess, L. R. Pomeroy, Gano Dunn, Charles Day, M. S. Rogers, Carl G. Barth and H. A. Horner.

BOSTON MEETING, APRIL 27

At a meeting of the Society in Boston, April 27, in which the Boston Section of the American Institute of Electrical Engineers and the Boston Society of Civil Engineers coöperated, a paper on The Testing of Water Wheels after Installation, by C. M. Allen, Mem.Am. Soc.M.E., was presented by the author, who illustrated it with lantern slides. R. A. Hale, John C. Parker, Dwight Porter, George E. Russell, H. K. Barrows, Henry D. Jackson, and Henry C. Daggett, discussed the paper.

ST. LOUIS MEETING, MAY 28

A meeting of the Society with the Engineers Club of St. Louis was held on May 28, in St. Louis. Edw. C. Schmidt, Mem.Am.Soc.M.E., presented his paper on Freight Train Resistance; its Relation to Average Car Weight, which was also given at the Spring Meeting of the Society. Through the courtesy of the University of Illinois, the Illinois Central Railroad and the Terminal Railroad Association.

the railway test car by which the data in the paper was obtained, was brought to St. Louis for the meeting and was open for inspection between two and five o'clock Saturday afternoon in the Eighteenth Street Yard of the Terminal Association. This car is equipped with all the apparatus necessary for carrying on train resistance experiments, as well as with auxiliary apparatus which facilitates the making of locomotive road tests, and during the tests the apparatus within the car makes autographically, upon a chart 36 inches wide, a record of drawbar pull, speed, time, air brake cylinder pressure, wind velocity and wind direction.

The paper was discussed by Robert Moore, F. B. Fisher, H. Wade Hibbard, F. W. Marquis, J. P. Clayton, Walter E. Bryan and Mr. Waterman.

BOSTON MEETING, JUNE 1

A meeting of the Society with the Boston Section of the American Institute of Electrical Engineers and the Boston Society of Civil Engineers, was held in Boston on June 1. A dinner to Lewis B. Stillwell, President of the American Institute of Electrical Engineers, preceded the meeting at which many prominent in engineering circles in New England were present.

At the general meeting which followed, President Stillwell made an address on the Conservation of our Natural Resources, special consideration being given to the subjects of water power and forestry. An extended discussion of the paper followed in which Geo. F. Swain, C. T. Main, Henry F. Bryant and A. E. Kennelly took part.

SPRING MEETING, ATLANTIC CITY, N. J.

The 60th meeting of the Society was held at Atlantic City, N. J., May 31–June 3, 1910, at the Marlborough-Blenheim, with an attendance of 135 members and 119 guests. The Committee on Meetings had arranged a strong professional program and the Local Committee, under the Chairmanship of James M. Dodge, contributed in various ways to the pleasure of the members and their guests.

PROGRAM

OPENING SESSION

Tuesday Afternoon and Evening, May 31

Informal reunion of members in the parlors of the Marlborough-Blenheim.

SECOND SESSION

Wednesday Morning, June 1

Business Meeting: Reports of committees, tellers of election; new business.

THE SHOCKLESS JARRING MACHINE, Wilfred Lewis.

Discussed by A. E. Outerbridge, E. H. Mumford and F. W. Taylor.

A COMPARISON OF LATHE HEADSTOCK CHARACTERISTICS, Walter Rautenstrauch.

Discussed by Carl G. Barth, F. W. Taylor, Oberlin Smith and John Fritz.

THE STRENGTH OF PUNCH AND RIVETER FRAMES MADE OF CAST IRON, A. L. Jenkins.

Discussed by James Christie, Walter Rautenstrauch, F. I. Ellis, Henry Hess, Oberlin Smith, Wilfred Lewis, J. S. Myers, S. A. Moss, George Westinghouse, John Fritz and E. D. Meier.

FINISHING STAYBOLTS AND STRAIGHT AND TAPER BOLTS FOR LOCOMOTIVES, C. K. Lassiter.

Wednesday Afternoon

Unassigned in order to give opportunity for sight-seeing.

Wednesday Evening

Entertainment on the steel pier.

THIRD SESSION

Thursday Morning, June 2

THE MECHANICAL ENGINEER AND THE TEXTILE INDUSTRY, H. L. Gantt.

THE ELASTIC LIMIT OF MANGANESE AND OTHER BRONZES, J. A. Capp.

Discussed by S. A. Moss, F. W. Dean and E. A. Uehling.

THE HYDROSTATIC CHORD, R. D. Johnson.

THE RESISTANCE OF FREIGHT TRAINS, Edw. C. Schmidt.

Discussed by T. S. Bailey, Wm. T. Raymond, S. A. Moss, F. W. Dean, H. G. Stott, G. N. Van Derhoef, H. R. Cobleigh, Wm. H. Bryan, F. J. Cole, W. F. M. Goss and J. B. Blood.

FOURTH SESSION

Thursday Afternoon

GAS POWER SECTION

Business meeting and Reports of Committees.

A REGENERATOR CYCLE FOR GAS ENGINES USING SUB-ADIABATIC EXPANSION, A. J. Frith.

Discussed by S. A. Moss, Wm. T. Magruder and Charles Whiting Baker.

GAS ENGINES FOR DRIVING ALTERNATING-CURRENT GENERATORS, H. G. Reist.

TWO PROPOSED UNITS OF POWER, Wm. T. Magruder.

Discussed by Wm. Kent, H. G. Stott, J. C. Parker and E. D. Dreyfus.

SOME OPERATING EXPERIENCES WITH A BLAST FURNACE GAS POWER PLANT, H. J. Freyn.

Discussed by A. E. Maccoun, Jos. Morgan, W. E. Snyder, H. G. Stott, E. A. Uehling, S. K. Varnes, H. G. H. Tarr, Edw. Rathbun, Jesse M. Smith and Charles Whiting Baker.

Thursday Evening

Reception, followed by conferring of Honorary Membership on Rear-Admiral George W. Melville, U. S. N., Ret., and a brief address by Admiral Melville. Dancing and refreshments.

FIFTH SESSION

Friday Morning, June 3

BALL-BEARING LINESHAFT HANGERS, Henry Hess.

Discussed by F. B. Gilbreth, H. J. Smith, F. W. Dean, J. Sellers Bancroft, C. J. Jackson, H. R. Cobleigh, Harrington Emerson and G. N. Van Derhoef.

EXPERIMENTAL ANALYSIS OF A FRICTION CLUTCH COUPLING, Wm. T. Magruder.

Discussed by H. J. Smith, G. N. Van Derhoef, E. P. Haines and Oberlin Smith.

AN IMPROVED ABSORPTION DYNAMOMETER, C. M. Garland.

Discussed by C. M. Allen.

CRITICAL SPEED CALCULATION, S. H. Weaver.

Discussed by Henry Hess, S. A.Moss and M. Nusim.

COMMITTEES OF THE SPRING MEETING

LOCAL COMMITTEE

JAMES M. DODGE, *Chairman*

J. SELLERS BANCROFT
JOHN BIRKINBINE
J. C. BROOKS
WM. C. BURNHAM
HARRY W. CHAMPION
JAMES CHRISTIE
WALTON CLARK
MORRIS L. COOKE
CHARLES DAY
J. J. DEKINDER
KERN DODGE
FRANCIS H. EASBY
PETER EHLERS
THEO. N. ELY
THOMAS M. EYNON
STANLEY G. FLAGG, JR.
JOHN FRITZ
HARRIS R. GREENE
G. T. GWILLIAM
E. P. HAINES
ROBERT E. HALL
JAMES T. HALSEY
HENRY HESS
EDWARD I. H. HOWELL
ARTHUR C. JACKSON
WILLIAM C. KERR
WILFRED LEWIS
E. P. LINCH
CHAS. LONGSTRETH
THOMAS C. MCBRIDE
CHAS. E. MACHOLD
D. T. MACLEOD
EDGAR MARBURG
GEO. W. MELVILLE
EDWIN A. MOORE
HENRY G. MORRIS
JOHN S. MUCKLE
JOHN C. PARKER
F. R. PLEASONTON
A. H. RIDELL
T. F. SALTER
OTTO W. SCHAUM
COLEMAN SELLERS, JR.
OBERLIN SMITH
H. W. SPANGLER
A. A. STEVENSON
FRED. W. TAYLOR
GEO. E. TITCOMB
J. A. C. L. DETRAMPE
WM. S. TWINING
HAROLD VAN DUZEE
LINCOLN VAN GILDER
WILLIAM R. WEBSTER
TILDEN WHITE
WALTER WOOD
J. E. ZIMMERMAN

EXECUTIVE COMMITTEE

JAMES M. DODGE, *Chairman*

J. SELLERS BANCROFT — ARTHUR C. JACKSON
HENRY HESS — HENRY G. MORRIS
OBERLIN SMITH

FINANCE COMMITTEE

J. SELLERS BANCROFT — WM. S. TWINING
OBERLIN SMITH — WALTER WOOD

RECEPTION COMMITTEE

Tuesday Evening

HENRY G. MORRIS, *Chairman*

WM. R. CONRAD — EDW. P. HAINES
KERN DODGE — T. F. SALTER
J. A. C. L. DETRAMPE

Wednesday Afternoon and Evening

THOMAS C. MCBRIDE, *Chairman*

THOS. EYNON — JOHN S. MUCKLE
JAMES T. HALSEY — JOHN C. PARKER
WM. R. WEBSTER

LADIES' RECEPTION COMMITTEE

MRS. CHARLES DAY, *Chairman*

MRS. J. SELLERS BANCROFT — MRS. CHAS. LONGSTRETH
MRS. JOHN BIRKINBINE — MRS. THOS. C. MCBRIDE
MRS. MORRIS L. COOKE — MRS. HENRY G. MORRIS
MRS. J. J. DEKINDER — MRS. JOHN S. MUCKLE
MRS. JAMES M. DODGE — MRS. OBERLIN SMITH
MRS. KERN DODGE — MRS. F. W. TAYLOR
MRS. THOMAS M. EYNON — MRS. GEO. E. TITCOMB
MRS. HENRY HESS — MRS. WM. S. TWINING
MRS. A. C. JACKSON — MRS. JAMES WOOD

ACCOUNT OF THE MEETING

In place of the usual reception, the Spring Meeting at Atlantic City opened on Tuesday evening, May 31, with an informal reunion of members and guests in the parlors of the Marlborough-Blenheim, the Convention headquarters. Henry G. Morris, Chairman, Wm. R. Conrad, Kern Dodge, Edward P. Harris, T. F. Salter, and J. A. C. L deTrampe, made up thecommittee in charge. Throughout the whole. Convention an air of informality and freedom pervaded, permitting the renewal of friendships and the forming of acquaintances without the necessity for attending set functions and without the sense of being formally entertained.

Business and Professional Meeting Wednesday Morning, June 1

The meeting of Wednesday morning was called to order at ten o'clock by President Westinghouse. The report of the tellers of election was received and the names presented duly declared elected to membership in the Society. This list appears in the Annual Report of the Council published elsewhere in this volume.

The following amendments to the Constitution were proposed by the Tellers on Amendment to the Constitution, and adopted by the meeting:

C 10 An Associate shall be thirty years of age or over. He must have been so connected with some branch of engineering or science, or the arts, or industries, that the Council will consider him qualified to coöperate with engineers in the advancement of professional knowledge.

C 11 A Junior shall be twenty-one years of age or over. He must have had such engineering experience as will enable him to fill a responsible subordinate position in engineering work, or he must be a graduate of an engineering school. A person who is over thirty years of age shall not be eligible to membership in the Society as a Junior.

C 45 The Standing Committees of the Society to be appointed by the President shall be: Finance Committee, Committee on Meetings, Publication Committee, Membership Committee, Library Committee, House Committee, Research Committee, Public Relations Committee.

Following this there was a discussion on a proposed Bill for Licensing Engineers, introduced in the recent session of the New York Legislature. In explanation, Charles Whiting Baker, chairman of a committee appointed by the Council to investigate the subject, explained that the bill had called for the licensing of all grades of civil engineers, but that afterwards it was extended to all branches of engineering, requiring engineers to pass an examination and pay a license fee of $25 for the privilege of practicing in their profession. The Board of Regents would have authority to appoint a special board of examiners before which every engineer desiring to practice would have to pass an examination. The engineering colleges of New York would be under the control of the same Board of Regents.

It was felt that the passage of such a bill would be injurious and a number of prominent engineers appeared at Albany in opposition and owing to their representations the bill was withdrawn by its promoter, with the understanding that it would be amended and offered at a later time.

The special committee appointed by the Council had met and adopted resolutions upon the subject of the pending bill, substantially as follows:

That it is the sense of this committee that legislation affecting the privileges and status of engineers can be most wisely originated by conference between legislators and representatives of the national engineering societies, and that the attention of legislators proposing legislation be invited to this procedure as natural and regular.

To request the Council of the Society to communicate with the Committee on Education to request the State Assembly that further action on this bill be postponed until after the Spring Meeting of The American Society of Mechanical Engineers, to be held in Atlantic City, May 31–June 3, at which meeting the subject will receive discussion.

To request the Secretary of the Society to confer with his colleagues, secretaries of the foreign technical societies, and seek to obtain as much information as possible in regard to the necessity of the possession of certificates of competency, or other forms of license.

At a meeting of the Council just held at Atlantic City, a new Committee of Public Relations was authorized, one of the duties of which will be to act on any further legislation affecting the interests of members of the engineering profession. The movement for licensing engineers is bound to come up repeatedly in the legislatures of the various states and this Society should be prepared to take whatever action may be necessary to protect the interests of the profession as a whole from unwise and injurious legislation. This discussion ended the business meeting and the remaining time was devoted to the professional session.

There were four papers presented on the subject of Machine Construction and Operation. The first, The Shockless Jarring Machine, by Wilfred Lewis, dealt with a new type of jarring machine in which the shock heretofore transmitted to the ground is absorbed as effective work by the machine itself, saving substantially all ramming time and opening the way to other economies. The paper was discussed by A. E. Outerbridge, E. H. Mumford and F. W. Taylor.

Walter Rautenstrauch followed with his paper on A Comparison of Lathe Headstock Characteristics, concerned with the determination of the adaptability of a number of engine lathes to the economic performance of a standard task, that of taking a predetermined area of cut on all diameters of work of mild and soft steel pieces, with high-heat steels, and showed the attempts of different manufacturers to meet the conditions favorable to these steels.

Carl G. Barth, F. W. Taylor, Oberlin Smith and John Fritz discussed the paper.

The paper by A. L. Jenkins, on The Strength of Punch and Riveter Frames Made of Cast Iron was next presented, giving a résumé of the important theories proposed for the analysis of stresses in straight cast-iron beams and presenting data on tests with small castings similar in shape to punch frames which showed a failure to verify any formula. The discussors were James Christie, Walter Rautenstrauch, F. I. Ellis, Henry Hess, Oberlin Smith, Wilfred Lewis, J. S. Myers, S. A. Moss, George Westinghouse, John Fritz and E. D. Meier.

The fourth paper was upon Finishing Staybolts and Straight and Taper Bolts for Locomotives, by C. K. Lassiter, of Richmond, Va., and showed the advantage, in finishing staybolts, of automatically reducing in the center during the threading operations. Turning and facing the under head of straight and taper bolts were also treated. This paper was presented by E. D. Meier, who added a few remarks.

Wednesday Afternoon and Evening

Wednesday afternoon was left free for recreation, roller chairs for the boardwalk being provided throughout the afternoon by the Local Committee. At three o'clock a special car conveyed members and guests to the grounds of the Golf Club at Pleasantville, where those who desired went over the course. Afternoon tea was served by the ladies.

In the evening there was a large attendance at the entertainment on the steel pier for which admission had been arranged. The Committee in charge consisted of Thos. C. McBride, Chairman, Thos. M. Eynon, James T. Halsey, John S. Muckle, John C. Parker and Wm. R. Webster.

Gas Power Section, Thursday Morning, June 2

J. R. Bibbins, Chairman of the Gas Power Section, called the meeting to order at ten o'clock and a few remarks were made by Secretary Rice congratulating the Section on its activities. Following the business of the meeting, a paper on A Regenerator Cycle for Gas Engines using Sub-Adiabatic Expansion was presented by A. J. Frith, which described a new cycle of 100 per cent theoretical efficiency, caused by the expansion line being steeper than that caused by free expansion, showing an avoidance of the loss of heat by water

cooling, which in the older regenerative cycles overbalances the theoretical economy. The paper was discussed by S. A. Moss, Wm. T. Magruder and Charles Whiting Baker.

The second paper was on Gas Engines for Driving Alternating-Current Generators, by H. G. Reist, and brought out no discussion. The paper dealt with the solution of the problems of obtaining the best parallel operation of alternating-current generators when driven by means of gas engines, the most satisfactory solution being so to design the gas engine as to obtain nearly even rotation.

Two Proposed Units of Power, by Wm. T. Magruder, was next presented and criticized the existing usage, proposing instead the terms boiler-power and gas-power, both of which were defined and described. Discussion was offered by Wm. Kent, H. G. Stott, J. C. Parker and E. D. Dreyfus.

The fourth paper presented was upon Operating Experiences with a Blast Furnace Gas Power Plant, by H. J. Freyn, and contained a most complete account of elaborate tests made on the plant, extending over a period of two years. It was dicussed by A. E. Maccoun, Jos. Morgan, W. E. Snyder, H. G. Stott, E. A. Uehling, S. K. Varnes, H. G. H. Tarr, Edw. Rathbun, Jesse M. Smith and Charles Whiting Baker.

Professional Session, Thursday Afternoon

At the session of Thursday afternoon, commencing at two o'clock, four papers on miscellaneous subjects were presented, the first upon The Mechanical Engineer and the Textile Industry, by H. L. Gantt. This was designed to point out a field and its possibilities in which the mechanical engineer had done little, that of industries which have not ordinarily come under his surveillance. There was no discussion.

A paper on the Elastic Limit of Manganese and Other Bronzes, by J. A. Capp, followed, dealing with the elastic curves of brasses and bronzes, which are smooth curves, gradually bending as stress increases, and showing their lack of relationship to the elastic limit indicated by the elastic curve. S. A. Moss, F. W. Dean, F. B. Gilbreth and E. A. Uehling discussed the paper.

The Hydrostatic Chord, by Raymond D. Johnson, Niagara Falls, N. Y., was next presented. The name hydrostatic chord is given to a novel shape for large pressure conduits, the function of which is to produce a tendency in the pipe to round out after the pressure reaches a certain mean value, causing an effort to increase the vertical diameter and tending to lift both the dead weight of the pipe shell itself

and the top fill. The paper contended that these defects could be obviated with a shape properly designed on correct hydrostatic principles. There was no discussion.

The last paper was by Edw. C. Schmidt, on The Resistance of Freight Trains, and presented the results of tests made to determine this resistance and fully displayed and examined the test data. T. S. Bailey, W. T. Raymond, S. A. Moss, F. W. Dean, H. G. Stott, G. N. Van Derhoef, H. R. Cobleigh, Wm. H. Bryan, F. J. Cole, W. F. M. Goss and J. B. Blood discussed the paper.

Thursday Evening

On Thursday evening Honorary Membership in the Society was conferred on Rear-Admiral George W. Melville, U. S. N., Retired. At a gathering in the solarium of the hotel, Secretary Rice made formal announcement of the vote of the Council receiving Admiral Melville into such membership, and President Westinghouse voiced the pleasure of the Society in thus recognizing so distinguished an engineer. In replying, Admiral Melville expressed his appreciation of the honor bestowed upon him by his brother engineers. Sir William H. White, Past-President of The Institution of Mechanical Engineers and an Honorary Member of the Society, followed Admiral Melville and spoke of his splendid years of service to his country, of the sort sometimes disregarded by a man's own countrymen because of lack of perspective. He recalled the extraordinary naval experiences which the Admiral had undergone, in which he never at any time flinched from duty, and expressed himself in accord with Admiral Melville's feeling with regard to the honor conferred on him, since he also had been so signalled out by the Society. Walter M. McFarland then read an address prepared by Admiral Melville for the occasion, on The Engineer's Duty as a Citizen.

A reception followed at which the membership were given an opportunity to meet Admiral Melville and Sir William White, and dancing and refreshments concluded the evening.

Friday Morning, June 3

At the final session of the convention, held at ten o'clock Friday morning, four papers on Power Transmission were presented. The first, Ball-Bearing Lineshaft Hangers, by Henry Hess, gave in detail the actual and relative first cost of a lineshaft installation, with plain

bearings and ball bearings, and showed the saving secured by the latter. It was discussed by F. B. Gilbreth, H. J. Smith, F. W. Dean, J. S. Bancroft, C. J. Jackson, H. R. Cobleigh, Harrington Emerson and G. N. Van Derhoef.

Following this, Wm. T. Magruder, presented his paper on An Experimental Analysis of a Friction Clutch Coupling, giving the results of five lines of investigation. It was discussed by H. J. Smith, who illustrated his discussion with lantern slides, G. N. Van Derhoef, E. P. Haines and Oberlin Smith.

A paper by C. M. Garland, on An Improved Absorption Dynamometer, was next presented, describing a type of eddy-current dynamometer, adapted for the absorption of power given out by motors under test, with an enumeration of the conditions that should be fulfilled. C. M. Allen discussed the paper.

The fourth and last paper was by S. H. Weaver, on Critical Speed Calculation, treating of the properties of equations of vibration, with curves showing the amplitude of vibrations at different speeds for various shaft loadings, spans and bearing supports. Henry Hess, S. A. Moss and M. Nusim discussed the paper.

Following the professional session, Jesse M. Smith, presented the following resolution of thanks, which was unanimously adopted.

RESOLUTION OF THANKS

Whereas The American Society of Mechanical Engineers at the Semi-Annual Meeting held at Atlantic City in May–June 1910, desires to express its appreciation to those who have so bountifully provided for the entertainment of the visiting members,

Be It Resolved that the Secretary be instructed to extend the thanks of the Society and express the appreciation of its members and guests, to the local committees or their untiring efforts in providing for the comfort and pleasure of the visiting members.

Entertainment

During the entire convention roller chairs for the boardwalk were made available to the membership and admission furnished to the Golf Course at Pleasantville and to the entertainments on the piers.

The Ladies' Committee, under the Chairmanship of Mrs. Charles Day, contributed in every possible way to the pleasure of the visiting ladies throughout the meetings, and tea was served at the headquarters at the Marlborough-Blenheim, on Tuesday, Wednesday and Thursday afternoons, to which the members were also invited.

No. 1274

DEDICATION OF MEMORIAL TABLET TO ROBERT HENRY THURSTON

A bronze memorial tablet to Dr. Robert Henry Thurston, first president of The American Society of Mechanical Engineers, was dedicated at the New York monthly meeting, Tuesday evening, February 8, 1910, in the auditorium of the Engineering Societies Building, in the presence of many associates and former students of Dr. Thurston as well as of members of the Society. This bas-relief, the work of Herman A. MacNeil, a former student and personal friend of Dr. Thurston, a replica of the memorial tablet presented to Sibley College, Cornell University, by alumni and students, was placed in the rooms of the Society through the generosity of members, as an expression of their devotion to Dr. Thurston. The contributions were received by a committee consisting of John Fritz, S. W. Baldwin, Prof. R. C. Carpenter, Walter C. Kerr, E. A. Uehling, Wm. Hewitt and Gus. C. Henning; and the details connected with the acquiring of the tablet, its installation and the arrangement of the dedicatory exercises, were in the hands of Dr. Alex. C. Humphreys, Chairman, Chas. Wallace Hunt, Fred J. Miller, Prof. R. C. Carpenter and J. W. Lieb, Jr.

The program of the evening was designed to cover the various phases of Dr. Thurston's brilliant career, treated in each case by a speaker of wide reputation who had known Dr. Thurston intimately during this period of his life. It therefore very appropriately included an address on Dr. Thurston's relationship with the Society, by Prof. John E. Sweet, President of the Society from 1883–1884 and active with Dr. Thurston in its organization; a communication on Dr. Thurston's career as a naval engineer, from Rear-Admiral Benjamin Franklin Isherwood, U.S.N., Retired, Honorary Member of the Society, which was read by Prof. F. R. Hutton, Honorary Secretary; an address on Dr. Thurston at the Naval Academy at Annapolis, by Rear-Admiral George W. Melville, U.S.N., Retired, Honorary Member and Past-President, of the Society on Dr. Thurston as professor at Stevens Institute of Technology, by Col. E. A. Stevens,

trustee and treasurer of Stevens Institute and son of its founder; on Dr. Thurston's literary and research work, by William Kent, one of the organizers of the Society and a close friend and co-worker with Dr. Thurston; and on Dr. Thurston as director of Sibley College, Cornell University, by Walter C. Kerr, a trustee of Cornell. The Chairman of the Thurston Memorial Committee, Dr. Alex. C. Humphreys, president of Stevens Institute of Technology, presided over the meeting.

After the addresses of the evening, members and guests proceeded to the eleventh floor where the tablet was unveiled and presented by Dr. Humphreys, on behalf of the committee, to the Society, for whom it was accepted by Col. E. D. Meier, Vice-President. Colonel Meier declared this to be the first bronze statue of an eminent engineer erected in the United States in a great building devoted entirely to engineering and said that an excellent choice had been made in Dr. Thurston as a representative of his profession. Dr. Humphreys also presented to the audience Herman A. MacNeil, the artist, who made the concluding remarks of the evening.

It was a matter of regret that Mrs. Thurston found it impossible to be present at the meeting. A letter was read by the Chairman, expressing her appreciation of the honor rendered to Dr. Thurston. Messages were also received from President Westinghouse, who was prevented by urgent business from attending, and from Chief Engineer Chas. H. Manning, U. S. N., and Lieut.-Commander Robert Crawford, U. S. N., associated with Dr. Thurston in the Naval Academy at Annapolis.

The addresses of the evening follow.

INTRODUCTORY REMARKS

By Dr. Alex. C. Humphreys, Chairman

Member of the Society; President of Stevens Institute of Technology

While recognizing that it is not the function of a presiding officer to forestall the speakers to be introduced, I cannot refrain from saying a few words about my friend and preceptor, Robert H. Thurston. Others will tell you of his widely varied activities, his tremendous capacity for work, which was nevertheless overtaxed, his quickness of brain and speech, his powers of exact determination and expression, his capacity for organization and execution, his eminence as an engineer and educator. I prefer to think of him as the large-hearted, gentle, lovable, helpful man, the man of vision, the optimist.

While a student at Stevens, I was not fortunate enough to have Dr. Thurston's guidance during my junior year, for then, in 1879, he had not yet recovered from the almost fatal nervous breakdown, which resulted from his strenuous life in many lines of activity. But I came to know him well during my senior year, and had many occasions to be deeply grateful to him for his assistance and encouragement, which I then greatly needed. I never saw him other than cheerfully responsive to a request for help, and I was never allowed to feel that I was intruding when I went to him for counsel. While demanding respect and obedience from those under him, his attitude towards them was characterized by a sympathetic desire to be helpful.

Wm. Kent, one of the speakers of the evening, in his masterly biographical notice of Dr. Thurston in the Sibley College Journal, in writing of the vast amount of work performed at a certain time by Dr. Thurston, says: "And during all this time, I never saw him excited or ruffled over his work." We busy, overcrowded men, know this to be high praise indeed.

I met Thurston too seldom after I graduated from Stevens, but when we did meet, I was made to feel that he was really interested in my career, and that he rejoiced and sympathized with me as circumstances suggested. I like to remember that he came down from Cornell at the time of my inauguration as president of Stevens Institute, and that it was through him that Cornell University and Sibley College conveyed their good wishes to Stevens Institute and to me at that time. Later in that year he quietly passed away to his well-earned rest.

Thurston was a man of vision. Time and again this is shown in his writings, and especially in view of later developments. And this, notwithstanding that his declared results were sometimes afterwards amended, as must be the case with those who are courageous enough to act the part of pioneers.

We are, apparently, now only beginning to appreciate in this country the practical and commercial value, to say nothing of higher things, of technical and technological education. And even now, those who do have the appreciation are unable to move and guide those who have the power to provide the means for the necessary improvement in our educational methods. Years ago, Thurston wrote: "Germany has substituted for the now obsolete apprenticeship system, the systematic, scientific methods of preparing her youth for the future of their lives in all departments of instruction and industry."

He was a student of political economy and education and pointed

out the evils which would come to us unless certain lines of reform were followed, the evils which are now upon us and have to be met by patience, wisdom, firmness and common sense.

It was said of his father: "Throughout his life, his benevolence, his uniform kindness to employes and to all with whom he came in contact, and his strong attachment to his friends, made him as universally beloved as he was widely known."

The son was strong in faith though he did not carry his religion in his sleeve. He gave voice to his faith in a certain article which received wide attention, entitled, The Scientific Basis of Belief. It seems to me that the summation of his creed is found in a verse which he included in this article:

> Strong Son of God, immortal love,
> Whom we, that have not seen Thy face,
> By faith, and faith alone, embrace,
> Believing where we cannot prove.

Notwithstanding his great and varied accomplishments, it is as the holder of this faith, and as the worthy son of this worthy father, that I love to think of Robert H. Thurston.

DR. THURSTON'S CONNECTION WITH THE SOCIETY

By John E. Sweet

Honorary Member and Past-President, Am.Soc.M.E.

We meet tonight to do honor to the first president of The American Society of Mechanical Engineers, elected now nearly thirty years ago. I have been asked to tell the simple story of his connection with the Society. It is fitting that we whose fading memories can give only shadowy reviews of past events do the best we can to record the facts as we recall them.

To begin at the beginning, we must hark back to the fall of 1879, when the American Machinist was published in a small office at 96 Fulton Street, New York. The journal had been in existence but a few years. It had received contributions from a goodly number of contributors engaged in various branches of mechanical industries and from a wide section of the country. But very few of these contributors were known to the publishers, and fewer still to one another, and the notion came to my mind to get as many of them together as we well could, and give the publishers a surprise party; with a faint notion that it might lead to an organization. I conveyed

the notion to one of the contributors, and he at once gave it away to the editor, with the suggestion that some sort of a mechanical association be formed. The suggestion took root in the minds of the publishers, and Mr. Bailey, the editor, came to Syracuse to see me about it; or, in fact, to inveigle me into writing the invitations.

Among those invited were Alexander L. Holley and Prof. Robt. H. Thurston of Stevens Institute, then in a sanitarium in Dansville, N. Y., both of whom entered heartily into the scheme. Before the meeting, which was held on February 16, 1880, Mr. Bailey and I had an interview with Mr. Holley; each was to draw up some form of program for the meeting, and we were to meet the next day to compare notes. As such things usually turn out, Mr. Holley had drawn up a set of rules which were so complete that we could readily endorse them. At the meeting in the afternoon there were something like thirty present, with letters of endorsement from fifteen or twenty others. Mr. Holley acted as chairman, and I well remember the point he made in his opening address, that it had come to that state of affairs that both civil and mining engineering were largely mechanical. A good deal of time was spent in discussion of the rules, which ended in the adoption of those Mr. Holley had prepared; and time was also wasted in settling on a name, until Mr. Copeland said, "Call it 'The Society of Mechanical Engineers.'" This seemed to settle it, except that in the shuffle the word "American" got incorporated, to the regret of possibly no one but myself.

Mr. Copeland, Charles T. Porter, Mr. Holley, E. D. Leavitt, Jr., and myself were chosen as a nominating committee. The officers nominated were elected at the meeting held April 7, 1880, at the Stevens Institute, over which Henry R. Worthington presided.

At the time of what is now known as the first annual meeting, held in New York, November 4 and 5, 1880, Professor Thurston had regained his health, and was able to preside and to deliver an able address. Professor Thurston was elected president for the second time, and these two were the critical years in the Society's history. We then held three meetings a year, and while Holley and Worthington lived, they formed with Professor Thurston a three-point support that did not rock; but they both died while Thurston was President, and left him to carry the burden. One incident that occurred during this time I shall always remember. Going out from one of the meetings Mr. Worthington, greatly elated over the way things were moving, said to me, "Professor, the thing is going to go." I doubt if any of us had the idea that the Society

would reach a membership of 300, while today it takes more than another right-hand cipher added to our figures to record our membership.

Professor, later Dr. Thurston, not only while president, but for a long time later, was more instrumental in helping up the Society than any other man. It is not necessary to enumerate his contributions to the Transactions. He never showed evidence of elation at success or chagrin at defeat. His work enriches every volume of the Transactions, from the first volume down to the time of his death. And every member of the Society needs to open the door of his memory and let the history of its work shine in and enliven his spirit of respect and adoration for the boy, the student and the scholar, the thinker and the worker, the teacher and the guide, the honored member and revered first president of The American Society of Mechanical Engineers, and the man—Dr. Robert Henry Thurston.

DR. THURSTON'S CAREER AS A NAVAL ENGINEER

By Rear-Admiral Benjamin F. Isherwood, Engineer-in-Chief, U. S. N., Retired

Honorary Member, Am. Soc. M. E.

Professor Thurston, in whose honor these commemoration exercises are held, was in all respects an exceptional person, with endowments not only of a very rare but of a very high order. He was a typical representative of the American engineer of the present day; combining a thorough and extensive practical knowledge of his profession with a scientific culture scarcely found in the exclusively theoretical scientist; and he had, in addition, the ability to make these qualifications available to the world by means of an excellent literary education improved by a carefully discriminating practice as a writer, an orator, a mathematician, and an original investigator in the broad field of his profession. The first-class engineer of the present day must also be a first-class scientist as well as a first-class mechanician, besides possessing a mind well stored with the information collected by others of his profession whose aims and achievements are similar to his own.

With these mental powers was associated, in the case of Professor Thurston, so charming a personality that he not only never had a foe, but all who knew him were his friends. His knowledge and his services were at the command of all who sought them, and were

rendered in a manner that made the recipient believe that instead of receiving a favor, he was conferring one. Professor Thurston was the author of several books on engineering subjects, which were classics in their day. He was also a prolific investigator of difficult phenomena in engineering, and his numerous reports have much enriched its literature and enlightened its obscurities. He wrote with perspicuity, elegance and ease; and he was a ready and fluent orator on all the scientific topics of the day.

His death was a great loss to the world, and particularly to his own profession of engineering, for his exceptionally valuable life was devoted to the improvement of the world in the only way it could, in his opinion, be improved, namely, by the cultivation of physical science. Great intellectual attainment meant with him, great everything else.

Those who knew Professor Thurston best valued him the highest. My personal acquaintance with him was long and intimate, and it was intensified by our professional interest in the same subjects, notwithstanding the great difference of our ages and temperaments; and none who knew him as well as I did will consider this weak portraiture of him as overcolored. His death at Cornell saddened all who knew him well enough to appreciate his gentle qualities, as well as his lofty aspirations. He was most happily constituted; he lived his life in the sunshine of an entirely normal existence, and by dying in the full flush of manhood and in the consciousness of great achievement, he was saved from decline, and enabled to pay to glory the debt he owed to nature.

DR. THURSTON AT THE NAVAL ACADEMY AT ANNAPOLIS

By Rear-Admiral George W. Melville, U.S.N., Retired
Honorary Member and Past-President, Am.Soc.M.E.

My function is to pay the tribute of the navy to one who was for a time a naval officer and who during his career as such bore himself in a way worthy of its best traditions, leaving a record, the memory of which is still distinct with those of us who were his contemporaries, although it has long since been overshadowed by the greater reputation of his more mature life.

When the engineer came into the navy, he received scant recognition, although we were very fortunate indeed in having as our first representative that grand old man, Charles H. Haswell, who was

taken from us so recently. The dominant faction in the navy did not like machinery nor mechanics, and as a result the very early engineers were largely men whose theoretical training did not go beyond the common schools and whose professional training came from hard knocks in the machine shop. This was true in my own case and in that of the great majority of the older engineers. At the breaking out of the Civil War, however, with the increased demand for engineers and the desire of patriotic men with engineering training to render their best service to the Government, a number of men came into the corps who were college graduates, and Dr. Thurston was one of these. He entered the service in July 1861, very soon after the beginning of hostilities and before any of the great naval battles, and he served at sea continuously until the close of the war, taking part in the Battle of Port Royal and in the Siege of Charleston. While still a second assistant engineer, he was placed in charge of the machinery on the Chippewa and later served on the monitor Dictator, the largest built up to that time.

The historian of the engineer corps of the navy, Past Assistant Engineer (now Captain) Frank M. Bennett, has mentioned several instances in which Thurston distinguished himself. One of these was on January 29, 1863, when he was in command of one of the armed boat's crews which captured the blockade runner Princess Royal at Charleston. The next day two armored rebel rams came down upon the Federal fleet and destroyed some of the converted merchantmen which constituted it. Thurston was temporarily chief engineer of the Princess Royal and by extraordinary efforts managed to get the machinery going so that she got out to sea and escaped destruction at the hands of the rebels.

With his fine preliminary training at Brown University and his four years of practical experience in the navy, it was obvious that he was well equipped for duty as instructor at the Naval Academy in the department of natural and experimental philosophy, to which he was ordered in 1865. During his term of service there, the head of the department died and Thurston was made acting head of the department.

It was during this time that the education of engineers at the Naval Academy began with the class of acting third assistant engineers who entered in 1866, of whom the late Admiral Rae was a member. Thurston undoubtedly gave instruction to all of these young engineers in that department, which we would now call thermodynamics, although he was not a member of the department of engineering

which looked after the more practical side of their professional training.

A retired engineer officer, who was an instructor at Annapolis in the department of engineering, while Dr. Thurston was in the department of physics, speaks of him as follows: "During about two years of his term at Annapolis, I saw him almost daily and am therefore able to bear testimony to the excellent work he then did both as an instructor and as the managing head of that very important department of our Naval School. He fully appreciated the importance of physical science to the naval profession generally, and its particular application to naval engineering, and he worked with untiring zeal for its full development as a part of the training of our young officers, often personally designing special apparatus, which were fewer then than now, for demonstrating physical truths and principles. Thurston was eminently fitted for this class of scientific work by taste, education and practical experience as a naval engineer.

At such a time as this, we realize how very interesting it would be if we could know exactly what circumstances lead to the selection of a man for a particular line of work. I have tried hard to find just what led to Dr. Thurston's selection for the chair of mechanical engineering in Stevens Institute, but it occurred so long ago, almost forty years, that the details are no longer available. Indeed it is probable that there never was any record of them and that it was a matter between President Morton and Dr. Thurston himself. Unless a man writes an autobiography, and is as frank about all the occurrences of his life as Herbert Spencer, such an interesting phase as this is apt to be entirely passed over in spite of its great importance. Aware, as those of us who knew him well are, of Thurston's marked ability as a scientific expositor and of his life-long desire for progress and increased efficiency, may we not imagine that, before he was asked to become President of Stevens, President Morton had become acquainted with Dr. Thurston through his articles; and by correspondence or conversation had found that here was a man after his own heart, who could be counted upon to make the new school of technology what he wanted it to be, the best in the country.

There were other departments of colleges and perhaps other schools where mechanical engineering was taught, but Stevens was, I believe, the first institution in our country devoted exclusively to the education of mechanical engineers, and we can now realize even better than when he was called to the Chair, how extremely important was the selection of Dr. Thurston for this work. If he had been content

to drift along in accordance with old established methods, or if he had not been a tremendous worker, his great ability would have failed to give to Stevens the foremost standing which it has held from the very start.

Dr. Thurston had, in a degree rarely found among men devoted to education, a strong touch of the commercial instinct, and it was doubtless this which led him, from the beginning, to direct the work of his students in their experiments along lines of an immediately practical interest to engineers and others. For example, I remember a set of experiments to determine the economy of gas engines at a time when they were just coming into use. This was only one of a great many instances. The hard-headed, practical manufacturers could not fail to realize that a school where the energies were directed in such a practical way must turn out men who would make good in practical life. I need hardly show that this judgment has been verified by recalling the positions now held by many of these graduates, in offices of the very highest importance in the lines of manufacturing and transportation.

So great was the reputation made by Dr. Thurston at Stevens, that he was generally looked upon as the greatest teacher of mechanical engineering in the country; and I happen to have information with respect to the circumstances under which he went to Cornell which shows that when they were looking for a man of the highest accomplishments to take charge of Sibley College, they at first did not consider Dr. Thurston, for the reason that they did not believe any inducement could take him away from Stevens. When the Trustees of Cornell came to the conclusion that they wanted the best man available, and that they were willing to pay whatever was necessary to secure his services, they eventually opened negotiations with Dr. Thurston, which led to his finally going there.

Of his splendid work at Cornell others will speak, and I need only say that it is a marvelous tribute to his ability and reputation that he should have been able to increase the attendance at Sibley College from about one hundred students to over one thousand.

His educational work was so engrossing that it naturally left him little time for keeping up his association with the Navy, although we who remained in the service always felt that in him we had a sincere friend on whom we could depend for such help, whenever needed, as it was in his power to give. Before we finally attained the full recognition of the paramount importance of engineering in the Navy, which, as you know,

is now the function of the entire line of the Navy, we had many an up-hill fight, and on several occasions Dr. Thurston materially assisted us by articles in the magazines and by personal appeal. In this connection it is interesting to note that Bennett's History of the Steam Navy, in speaking of an order of the Navy Department in 1870, which was considered very unfair to the engineer corps, mentions that, in consequence of this order, a number of the brightest men in the corps resigned, among them Dr. Thurston. It has been my observation that the participants in an up-hill fight are drawn more closely together than those whose association is always on the winning side. It was doubtless Dr. Thurston's keen recollection of the lack of recognition which he had received while an engineer in the Navy, that made him so willing to help those who were still in the service in their efforts for a proper recognition and consideration of engineering and its exponents.

It has been my desire as a naval engineer and one whose whole life has been spent in the naval service, to voice, in behalf of myself and my colleagues who were and are engineers in the Navy, our admiration for the friend who, during his own short naval career, did so much to add to the reputation of the engineer corps, and by his prominence as an engineer all through his life reflected the highest credit upon naval engineering.

DR. THURSTON AT STEVENS INSTITUTE OF TECHNOLOGY

By Col. E. A. Stevens

Member of the Society; Trustee and Treasurer of Stevens Institute

Thurston's work at Stevens can be divided into two parts: on the one hand his general work as an engineer, including his well-known contributions to the literature of engineering and the researches on which they rested; and on the other his share in the development of the work of the Institute and the influence of his personality on his fellow instructors and the undergraduates.

As to the first part I can say but little in the time assigned. The history of mechanical engineering in the United States will always bear witness to his ability, to his untiring energy and to the liberality with which he freely gave to his beloved profession all that his ripe experience and trained observation could give.

Whatever may have been the value of his other work while at

Stevens, none of it surpasses, or I may say equals in importance, his share in the development of the system of instruction and the influence of his personality and of his standard of professional ethics on those with whom he was there thrown into contact.

Forty years ago the American mechanical engineer was mainly the product of the shop and the engine room, with such self-teaching as could be gathered in the leisure hours of a busy life of hard work. Most engineers of that day would admit that drafting and mathematics could be taught in schools, but claimed that such training would produce draftsmen and mathematicians, not engineers, men who would be of less value in practical work than the lad of the same age who had spent his time in the shop; that the school-bred man would need several years of hard work to knock the school-taught nonsense out of his head, always granting that he had not been irretrievably ruined by his scholastic training.

Such was the general, even if not the unanimous mind of the profession when Henry Morton gathered around himself six men, who with him were to form the faculty of the first American school wholly devoted to the teaching of mechanical engineering. Scientist and scholar as he was, Morton appreciated the gravity and importance of the task set him and selected his fellow members of the faculty with a care and judgment amply justified in the result. Of these men, eminent as they were, Thurston was the one on whom devolved the practical teaching of engineering. The others must have aided, and unquestionably did aid, in giving the training as a whole a practical direction, but it was to Thurston more than to any one other of Morton's first faculty that the prominence of the practical curriculum at Stevens must have been due, and on him therefore it is but fair to bestow a generous share of the acknowledgment due these men. It would be as invidious as it would be useless to apportion to each the share due to his individual efforts.

While Thurston's personality impressed itself on all who met him, whether at Stevens or elsewhere, the lasting result of this impression on the men who there studied under and with him forms a part of the history of Stevens. The material that came to the "Old Stone Mill" was much the same in the early days as since. The early graduates at once took a standing in American engineering work that soon settled once and for all any debate as to the value of a technical training. They carried also with them into the world what was as necessary for the progress of engineering as technical skill or practical knowledge. They had imbibed together with their

calculus and thermodynamics that moral and ethical view of their profession without which an engineer's skill and learning is of little value to his country, a thing not absorbed from text books or taught by platitudes, however often reiterated from the lecture platform.

Boys and young men quick to detect cant are equally quick to recognize and value square-dealing and to love and follow and model themselves after the straightforward man. Of all of that first faculty there was no one to whom the undergraduates could and did more confidently look for a square deal than to Thurston. That straight clear gaze, right into your eye, gave at once a confidence in the man and in his methods that experience did not belie.

Single instances prove few cases and a life such as Thurston's is not to be judged by citing examples and incidents. The true measure of his great work and usefulness is the standard set by the great Master, "by their fruits ye shall know them." By no other standard would Thurston have asked to be judged and the fruits of his work at Stevens are proven not by the accomplishment of specially gifted men who studied under him but by the general standing of the Stevens men of this day.

DR. THURSTON IN LITERATURE AND IN RESEARCH

By Wm. Kent

Member of the Society

My acquaintance with Dr. Thurston began near the end of the year 1874, when I called upon him to make arrangements for entering the junior class in the Stevens Institute of Technology. He was then thirty-five years of age. He was at this time professor of mechanical engineering, meeting his classes two hours a day for, I think, five days in the week; he was editing the four volumes of reports of the United States Commission to the Vienna Exhibition of 1873, one of the volumes being written by himself; he had shortly before written a report of the United States Commission for investigating the causes of steam-boiler explosions; he was planning the researches to be made by the United States Board to test iron, steel and other metals, of which he was secretary and the most active member. Besides all this he was writing papers for the American Society of Civil Engineers and for the Journal of the Franklin Institute, concerning the results of his researches. In 1871 he had conducted a series of boiler tests on several different makes of water-tube boilers

at the American Institute fair in New York. In 1873 he had organized a mechanical engineering laboratory for the purpose of making engineering researches, the first of the kind to be established in the United States. At about the same time he invented his well-known autographic testing machine for testing materials by torsion, and later he invented a machine for testing lubricants, in which some of the principles of the torsion machine were embodied.

In June 1875, Dr. Thurston called me into his office and told me he wanted me to undertake a research into the strength and other properties of the alloys of copper. I said to him, "I don't know anything about alloys." "That is a good qualification," said he, "you won't have anything to unlearn." He told me how to make a research into the literature of the subject, and how to find indexes to such literature. He had me write him a report of all I could find that was then known about the alloys of copper and tin and copper and zinc, and after studying it he planned a series of tests to be made in the laboratory, which took eighteen months to complete. During all this time I had to report to him almost every day, and I had a desk in his office. Then began an intimate friendship which lasted until the day of his death. During these two years of companionship I was ever more and more impressed with Dr. Thurston's genius and with the breadth of his intellectual power. Not only was he a tireless worker, driving the pen or pounding the typewriter hour after hour, but his brain always seemed to be working as steadily and as rapidly as his pen. Whenever he was asked a difficult question the answer seemed to come instantly from his well-stored mind, and the answer was right. Such a combination of industry, rapid and clear brain-action, and broad intellectual grasp of a great variety of subjects, engineering and other, I have never known in any other man.

Such intense mental activity as Dr. Thurston exhibited in these years led to its natural result, nervous exhaustion. There was a time in 1876 when he visited the Institute only for a few minutes each day, and five minutes' conversation on any technical question would almost prostrate him. During this time he was worried by the fear that Congress would not continue the appropriation for the work of the United States Test Board, and he undertook to write a letter on the subject to one of the senators, but it took him a week or more to write the letter, working on it five minutes a day. He gave me a copy of it to take to one of the members of the board in New York City, and that member said to me that it was by far the best presen-

tation of the subject that had ever been made. Such was the quality of his work when he was on the verge of physical collapse.

Here is another example of the kind of work he could do during the same period. He had been planning a series of tests of the triple alloys of copper, tin and zinc, and one day on one of his brief visits to the Institute he said to me: "Here is something I want to show you. Here is an equilateral triangle. It is one of the properties of this triangle that if from any point within it perpendiculars are drawn to each of the sides the sum of these perpendiculars is equal to the altitude. Now let us mark one apex 100 copper, another 100 tin, and the third 100 zinc, and the opposite sides zero copper, tin and zinc. Then any point in the triangle represents one alloy, and all the possible points represent all the possible alloys of the three metals. Now divide each altitude into ten parts, and through the points of division draw lines parallel to the three sides. The crossing points of these lines represent all the alloys whose constituents are even multiples of ten per cent. We will make these alloys and determine their tensile strength, and we will cut a lot of straight wires to lengths corresponding to the strength; then we will set these wires vertically on a board which has the triangle drawn upon it, in holes drilled at the points representing the alloys. We will then fill in this forest of wires with plaster of paris, smoothing it off so as just to leave the tops of the wires visible. We will thus have a topography which shows the general law of the relation of the tensile strength of the triple alloys to their composition." I well remember my amazement when he had completed the description, that a man with such a worn-out brain should be capable of such a brilliant piece of intellectual work and invention. The investigation of the triple alloys was carried out exactly as he had planned it, and the results were published in the Reports of the United States Test Board, and in Dr. Thurston's book on Alloys.

In 1873 Dr. Thurston discovered the phenomenon of the elevation of the elastic limit of iron and steel. It was also discovered independently in the same year by Commander L. A. Beardslee, U.S.N. In the years following he tried to find other metals or alloys that exhibited the same peculiar action after being strained beyond their elastic limit, but never found one. In 1874 he investigated the burning of tan bark for fuel in specially constructed boiler furnaces, and in 1875 and 1876 he made a number of tests of steam boilers. For some years after 1876 he carried on investigations of lubricants, the results of which are in his book on Friction and Lost Work. In later

years his researches were not numerous or important, for the reason that his time was fully occupied with other work. It is a matter for lasting regret that the work of the United States Iron and Steel Test Board was discontinued almost before it was fairly started, and before the Watertown testing machine, which was built for its use, was finished.

Dr. Thurston was an omnivorous reader, and a tremendously active writer. Prior to 1880 most of his technical writings were contributed to the American Society of Civil Engineers and to the Journal of the Franklin Institute. After that date his engineering papers were mostly given to The American Society of Mechanical Engineers.

Dr. Thurston's literary work was not confined to engineering matters. In 1873 he contributed to the Scientific American a series of seventeen articles on his observations in Europe, which included not only what he had seen at the Vienna Exhibition, and in the several iron works that he visited, but also his reflections on social conditions in the manufacturing centers. Here is a quotation from his remarks on the inferiority of workmanship which then characterized many European productions:

> A liberalization of patent codes, and the gradual training of the workmen of Europe to a knowledge of the importance of good workmanship, and of the methods of securing it, will at a time which we hope is not far distant, do much toward the improvement of the condition of the people. We draw some of our best material from amongst them, and it seems sufficiently evident that not upon nature but upon man's own imperfect political systems lies the responsibility of the unsatisfactory condition of manufactures in Europe.

Dr. Thurston's first important book after his report of the Vienna Exhibition was his History of the Growth of the Steam Engine, published by Appleton in 1878. It is written in his best style, and to those who are at all interested in the subject it is as readable as a novel. It illustrates his painstaking care to be sure of his facts, his skill in arranging them in logical order, and his good judgment in drawing conclusions. In 1877 he brought out a little book on Steam Boiler Explosions in Theory and Practice.

In 1879 he had his second and last nervous breakdown, more serious than the first, so that he was compelled to spend more than a whole year in a sanitarium, doing no work of any kind. He returned to work in 1880, and then followed twelve years of most intense literary activity, during which he brought out an average of a book every year, some of them large octavos of 1000 pages. Here is a list

TRANSACTIONS
OF
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

VOLUME 32—1910

THIS volume contains the papers and proceedings of The American Society of Mechanical Engineers for the year 1910, covering the thirty-first year of the Society's history. A record of the work of the year is given in the annual report of the Council, presented at the Annual Meeting of 1910.

The newly-elected President, George Westinghouse of Pittsburg, was introduced, as is customary, at the Annual Meeting of the Society in December 1909, an account of which appeared in Volume 31 of Transactions, covering the proceedings of 1909.

GEORGE WESTINGHOUSE

George Westinghouse, President of the Society for 1910, was born at Central Bridge, N. Y., October 6, 1846. His father was a manufacturer of agricultural machinery, and established works at Schenectady, which are still in operation. The younger Westinghouse was educated in the public schools and at Union College, Schenectady, and received his early mechanical training in his father's manufactory. His tastes were strongly in the direction of machinery and the solution of mechanical problems.

The patriotic ardor which filled the youth of the country during the Civil War drew young Westinghouse into the volunteer army in June 1863. He was under seventeen, but on account of his size and strength—he was six feet tall and weighed 180 pounds—the recruiting officers admitted him. In December 1864 he became an assistant engineer in the United States Navy, serving in that capacity until August 1865.

Returning to civil life he invented in the same year a device for replacing derailed cars, and while placing this invention with the railroads his attention was attracted by the prevalence of minor and serious accidents due to the lack of efficient means for controlling trains in motion. After a careful study of the subject, and such experiments as were possible with the limited means then obtainable, he invented the air brake and patented it in 1868.

The first train to which this brake was applied ran on a line west from Pittsburg and on what is now a portion of the Pennsylvania Railroad. During the trial trip a collision with a loaded team stuck on a grade-crossing was prevented. This practical illustration of the utility of the invention led to the adoption of the brake. Mr. Westinghouse, retaining the control of his invention, undertook to manufacture it and organized the Westinghouse Air Brake Company, establishing at Pittsburg the business which subsequently became the nucleus of the many industries associated with his name. He later applied compressed air to switching and signalling and utilized electricity in this connection. From this grew the Union Switch and Signal Company.

His introduction of electricity into switch and signal work led him far into electrical experiment and he devoted his energies to a cause in which few then believed, the adoption of the alternating current for lighting and power, in which he had to meet and overcome almost fanatical opposition, which in many States sought legislation against the use of the alternating current as dangerous to the public welfare. In 1885 he acquired the patents of Gaulard & Gibbs, and having undertaken a comprehensive study of the distribution and utilization of electrical currents in a large way, he personally devised apparatus and methods for the work, and gathered around him a group of men who were to become experts in the new electrical art. He also organized the electrical company which bears his name and undertook the development and manufacture of the induction motor which made practical the utilization of the alternating current for power purposes.

Following the discovery of natural gas in the Pittsburg region, Mr. Westinghouse devised a system for controlling the flow and for conveying the gas over long distances through pipe lines, thus supplying fuel to the homes and factories of Pittsburg. He took up the study of the gas engine, and for ten years conducted a series of exhaustive experiments in this line, at the end of that time putting into commercial use a gas engine of large power for electric generating.

Mr. Westinghouse introduced the Parsons steam-turbine into this country, adding to it improvements and developments of his own, and others carried out under his supervision. He has also recently developed a steam turbine for ship-propulsion designed to overcome the well-known objections to the use of turbines in that field, and lately coöperated with Rear-Admiral Geo. W. Melville and John H. Macalpine in their study of problems associated with driving of propellers at low speed by turbines of high speed.

It is impracticable to enumerate here the inventions which Mr. Westinghouse has personally made or those which his staff have brought forth under his supervision. As a result of this work and enterprise, there have grown thirty corporations of which he is president, employing 50,000 men, and $120,000,000 of capital, with works at Wilmerding, East Pittsburg, Swissvale and Trafford City, Pa.; at Hamilton, Canada; London and Manchester, England; Havre, France; Vardo, Italy; and at Vienna and St. Petersburg.

Mr. Westinghouse has made many visits to Europe in connection with his inventions and industries. There as in his own country he has won the friendship of the foremost men of his time and the high esteem of the engineering profession. He has been decorated by the French Republic and by the sovereigns of Italy and Belgium; and he was the second recipient of the John Fritz Medal, Lord Kelvin, his friend of many years, having been the first. The Königliche Technische Hochschule of Berlin bestowed upon him the degree of Doctor of Engineering; and his own college, Union, gave him the degree of Ph.D. Besides his Honorary membership in The American Society of Mechanical Engineers, Mr. Westinghouse is one of the two honorary members of the American Association for the Advancement of Science and is an honorary member of the National Electric Light Association.

THE ANNUAL REPORTS OF THE COUNCIL AND STANDING COMMITTEES, 1910

THE REPORT OF THE COUNCIL

The Council presents the following summary of the activities of the Society, supplementing the reports of its Standing Committees, which are part of the report.

The Council has held nine meetings during the administration year, from December 1909 to December 1910.

HONORARY VICE-PRESIDENTS

In response to invitations representatives have been appointed on the following occasions:

National Civic Federation Conference on Uniform State Legislation, Washington, D. C., January 17–19
Jesse M. Smith, Chas. Kirchhoff, A. W. Burchard, E. G. Spilsbury, F. M. Whyte, Wm. H. Wiley.

Opening of the Forest Products Laboratory of the University of Wisconsin, Madison, June 4
Carl A. Johnson, J. G. D. Mack.

International Congress of Mining, Metallurgy, Applied Mechanics and Practical Geology, Düsseldorf, June 19-23
Charles Whiting Baker (also appointed from the Department of State as a delegate on the part of the United States).

Funeral of Charles T. Porter, Honorary Member, Auburn, N. Y., August 30
Alex. C. Humphreys, Hosea Webster, A. E. Forstall, J. E. McIntosh.

Second National Conservation Congress, St. Paul, Minn,. September 5–9
Paul Doty, J. J. Flather, L. H. Gardner, E. E. Johnson, M. E. R. Toltz.

National Irrigation Congress, Pueblo, Colo., September 26–30
C. H. Williams.

American Mining Congress, Los Angeles, Cal., September 26–October 1
H. H. Clark, Robert Linton.

Inauguration of President McVey, University of North Dakota, September 27–29
Calvin H. Crouch.

MEMBERSHIP

The changes in membership are shown in the following table:

GRADE	No. OCT. 1, 1909	LOSSES				ADDITIONS		NET INCREASE	No. OCT. 1, 1910
		Transfer	Resignation	Lapsed	Death	Transfer	Election		
Honorary	15	....	....	....	1	....	1	...	15
Members	2483	....	13	13	31	28	155	126	2609
Associates	394	28	5	4	5	1	40	decrease	393
Juniors	834	1	16	20	1	....	86	48	882
Total	3726	29	34	37	38	29	282	173	3899
Affiliates of Gas Power Section								....	145
Affiliates of Student Branches								318	512

The following resignations were accepted during the year 1909–1910:

Edgmont B. Arnold, Jno. S. Avery, Richard C. Beverley, Albert E. Coleman, Asa S. Cook, Carl S. Dow, Harry Dunn, L. Hodgson, A. E. Holcomb, Zareh H. Kevorkian, George E. Kirk, Wellington W. Kuntz, W. A. McFarland, Henry E. Paine, R. Raymond, E. G. Rust, Foster C. Slade, Henry J. Scales, L. Searing, Ephraim Smith, J. E. Tatnall, Chas. J. Wachalofsky, Arthur S. Wardwell.

Membership which has lapsed during the year 1909–1910:

Arthur T. Alexander, Elmer T. Barnard, Wm. W. Bigelow, Frederick A. Boland, F. E. Bradenbaugh, James Breen, Jas. M. Briggs, E. D. Clarage, John G. Dodwell, Wm. F. Donovan, L. H. Gardner, Jos. N. Gregory, H. H. Hanna, Jr., Geo. O. Hodge, G. L. Holmes, Nathaniel Lombard, Chas. F. Meissner, E. E. Miller, John L. Mohun, Rafael de la Mora, James Naughten, Harvey E. Newell, W. Allen Pendry, H. W. Pudan, J. D. Ramsay, Warren B. Reed, Cyrus W. Robinson, D'A. W. Roper, Frederic Albert Schroeder, Edward Seaver, Jr., Robert M. Snyder, E. O. Spillman, George W. Stewart, Alfred A. Thresher, Chas. Henry Umstead, C. L. Weil, A. J. Wiechardt.

Members deceased during the year 1909–1910:

Mark Bary, Stephen Baldwin, Chas. Batchelor, Wm. P. Bettendorf, Jas. H. Blessing, J. H. Bloomberg, Jas. W. Bridge, Wm. W. Churchill, Chas. B. Clark, Wm. E. Crane, B. Cruikshank, Chas. B. Dudley, J. D. E. Duncan, R. W. Emerson, Jas. B. Faulks, Jr., C. F. Foster, Chas. H. Ferry, J. Garbett, A. M. Goodale, L. C. Grover, H. S. Haskins, Walter C. Kerr, John E. McKay, Wm. Metcalf, F. J. Plummer, Wm. N. Parsons, Chas. T. Porter, I. I. Redwood, P. A. Sanguinetti, T. H. Savery, Horace See, Gardner C. Sims, J. Henry Sirich, Jr., Wm. W. Snow, E. P. Sparrow, A. Spies, Chas. Swinscoe, C. H. Willcox.

On approval of the Membership Committee, John T. Jones and B. H. Cameron have been reinstated.

The Council has elected to Life Membership, S. B. Whiting and W. F. Mattes, who have been Members ever since the formation of the Society; and George W. Melville, Rear-Admiral, Past-President of the Society, has been made an Honorary Member.

On the Spring and Fall Ballots the following new members were elected and changes in grade of others authorized:

Elected June 1, 1910, Atlantic City: Members. W. J. Best, F. A. Blakeslee, Edward W. Brown, William L. Bryant, Henry Kenyon Burch, W. R. Carson, Cloyd M. Chapman, H. B. Chapman, Frank H. Clark, H. I. Cone, E. S. Cooley, E. H. Coster, A. D. Cressler, Byron Cummings, W. J. Davis, John A. Doane, D. Dorward, Jr., M. C. Ernsberger, R. W. Fenn, Harwood Frost, George W. Fuller, J. W. Fuller, Jr., David L. Gallup, Albert F. Ganz., Edwin S. Hallett, John Hays Hammond, W. H. Herschel, Alec. W. Hodgson, U. T. Holmes, F. Kingsley, A. Lebrecht, C. R. Lester, Wm. J. A. London, Harrison Loring, Jr., Chas. G. Lundgren, Adolphus A. McLeod, W. G. Marot, Irving S. Merrell, Frank H. Metcalf, John F. G. Miller. Lewis F. Moody, J. Wm. Neidhardt,

Henry B. Oatley, Harry L. Parr, A. C. Paulsmeier, C. H. Peterson, Hollis P. Porter, Snowden B. Redfield, George R. Sanford, Eugene Y. Sayer, R. Schlatter, John J. Scollan, F. L. Sessions, W. C. Shallcross, Joseph D. Shaw, Elmer A. Sperry, Edson M. Stevens, Eliot Sumner, Theodore S. Tenney, W. E. Van Patten, V. S. Westcott, W. H. Whiteside, R. M. Wiggin, Paul Winsor, E. W. Wyatt, Lucien I. Yeomans, S. J. Zowski-Zwierzchowski. Promotion to Members. P. H. Batten, Frank Bishop, Jos. A. Bursley, Carl F. Dietz, R. W. Emerson, F. L. Kennedy, Roy Stevenson King, Frederick W. Mahl, S. M. Marshall, H. E. Satterfield, C. D. Young, John M. Young. Associates. Frank Burgess, S. P. Cobb, H. N. Cooley, Frank M. Sears, O. C. Thompson, Charles N. Thorn, Lawrence Whitcomb. Promotion to Associates. Wm. P. Hawley, Louis G. Henes. Juniors. M. L. Abrahams, John Adams, Alex. D. Bailey, Geo. A. Bancroft, Arthur F. Barnes, C. M. Barron. E. H. Bedell, Richard O. Bonner, J. B. Brady, Walter E. Brown, A. Bradley Burgess, Harold Thomas Carter, T. .D. Casserly, W. Van Alan Clark, H. H. Cook, William H. Cook, Glen H. Corlette, W. H. Correa, W. R. Crute, Geo. H. Cunningham, H. N. Davock, Ed. G. Dubarry, S. A. Ellenbogen, R. Emerson, H. V. Ennis, Stephen I. Fekete, J. O. Fisher, Walter J. Foley, George F. Gast, W. G. Gernandt, H. S. Gladfelter, Chas. C. Grant, Dwight K. Hall, H. D. Hartley, Fred M. Heidelberg, C. T. Henderson, Harry A. Hey ,Warren B. Hood, C. M. Husted, Austin D. Keables, H. B. Lange, W. H. Lines, J. Harold McCreery, H. B. McKibben, Thos. B. Morris, S. T. Mudge, B. S. Nelson, J. G. Painter, John H. Peper, Jr., William T. Price, Rudolph Roesler, Philip L. Ross, D. D. Rowlands, R. L. Rowley, R. P. Schoenijahn, J. T. Sharp, Jr., E. J. J. Sievers, Charles O'Conor Sloane, N. L. Snow, W. C. Sprau, R. K. Stockwell, Everett W. Swartwout, H. B. Taylor, Gerald E. Terwilliger, Charles Thoma, Jr., Walter Thoma, L. B. Webster, James L. Wick, Jr., R. A. Wilson, Forest E. Woodman, A. R. Zachert,

Elected December 7, 1910, New York: Members. Lawrence Addicks, Will H. Baltzell, H. H. Barnes, Jr., Dwight K. Bartlett, Oliver D. H. Bentley, John C. Bird, George Wright Bowers, H. A. Brinkerhoff, Willard Brown, Forest E. Cardullo, J. D. Carr, Markham Cheever, Howard B. Clark, F. B. Cockburn, Arthur E. Cutler, Hans Dalstrand, W. R. Dunn, Charles L. Edgar, William J. Edwards, W. W. Erwin, Edmund H. Farquhar, John Fisher, Benjamin D. Fuller, Halbert P. Gillett, Philip M. Hammett, F. M. Hartman, J. R. Henderson, Chas. H. Herrick, Lewis A. Howland, Allen Hubbard, George Francis Hutchins, Chas. T. Hutchinson, A. L. Johnson, G. R. Joughins, O. F. Junggren, P. Junkersfeld, Karl W. Knorr, Gustav L. Kollberg, J. W. Ledoux, Norman Marshall, Frank Amedee Nazzur, Warren E. Murray, Walter S. Myers, Charles L. Norton, M. Webb Offutt, Francis Conrad Osborn, Oscar P. Ostergren, Perley Burnham Palmer, Geo. U. Poole, Edwin Jay Prindle, M. H. Putnam, Edward B. Richardson, Charles H. A. F. L. Ross, Will M. Sawdon, Phineas V. Stephens, Sidney Stevens, James Balboa Stokoe, Julian B. Strauss, Wm. Barrett Updegraff, E. Victoreen, G. R. Wadsworth, E. L. Walker, D. E. Washington, William P. Westcott, C. T. Westlake, Thos. R. Weymouth, Richard T. Wingo, John J. York; Promotion to Members. John H. Damon, James E. Gibson, Henry John Hanzlik, Arthur C. Jackson, Horace Judd, Wm. H. Kavanaugh, J. H. Maysilles, H. A. Moody, James A. Pratt, Geo. F. Read, Jr., Theodore Howard Taft, J. W. Taylor, J. G. Vincent,

F. H. Vose, H. L. Whittemore, L. L. Willard. Associates. Freeman Field, Emil J. Heinen, M. T. Maguire, Ray Mayhew, John B. Perkins, W. R. Porter, G. E. Richardson, Arthur C. Scott. Juniors. John F. Allison, Edward E. Ashley, Jr., H. Harding Bailey, W. J. Bailey, T. D. Banks, Henry C. Beckwith, Harry Lewis Benner, Myron R. Bowerman, Wm. Wallace Boyd, Harry S. Brown, R. U. Bunker, Herbert W. Carey, F. A. Collins, Jr., P. E. Cowgill, Magruder Craighead, Peter A. Cummins, Charles Iven Day, H. L. Doolittle, H. Alfred Ellis, John Fallon, W. W. Fisher, Arthur P. Gerry, Frank J. Gordon, Lucian L. Haas, H. F. Hallock, L. G. Hanmer, R. C. Hargreaves, Eugene Hunt, Frederick W. Ives, John R. James, Reid Jones, John P. Kottcamp, Milton Kraemer, Chas. H. Leaman, Nixon Lee, W. E. McCann, J. P. McJilton, W. R. McKinnon, C. H. Mount, John P. Mudd, Albin J. Nott, Harry Ottinger, H. H. Ramsey, John I. Rogers, Jr., James R. Rossman, Jr., Chris. A. Shearer, A. F. Sinclair, Harry St. Clair Spillman, Glegge Thomas, Robert H. Tifft, Albert C. Townsend, Samuel K. Varnes, Joseph W. Wattles, 3rd, Erwin L. F. Weber, Hugo W. Weimer.

The Membership Committee have recommended this year for ballot 306 candidates, including 30 candidates for promotion, as compared with 339 last year, including 45 promotions. The general financial conditions prevailing in the country and the strictness with which the Committee is scrutinizing applications perhaps account for the slight falling off this year.

At the Spring Meeting amendments were adopted, the intent of which is to make the Associate grade no longer an intermediate grade between Member and Junior. These amendments appear in the report of the Constitution and By-Laws Committee.

STUDENT BRANCHES

The Council has been strict in its requirements for admission of Student Branches, and in general these are similar to those of the Carnegie Foundation for the Advancement of Teaching. There have been admitted to Student Membership since the last annual report, the University of Maine, Orono, Me., the University of Arkansas, Fayetteville, Ark., Yale University, New Haven, Conn., and Rensselaer Polytechnic Institute, Troy, N. Y.

PUBLIC RELATIONS COMMITTEE

An amendment to the Constitution was adopted at the Spring Meeting in Atlantic City which added the Public Relations Committee to the regular standing committees of the Society. The President appointed James M. Dodge, Past-President, Chairman, with associates, Robert W. Hunt, Past-President, Dugald C. Jackson, J. W. Lieb, Jr., Fred J. Miller. This committee will take up as one of its first

duties the report of the committee appointed by the Council to investigate the proposed bill before the legislature of the State of New York looking to the licensing of engineers.

The special committee consisted of Chas. Whiting Baker, Chairman, Leonard Waldo and Alfred Brooks Fry, and their investigations have brought out data on this in foreign countries.

PUBLICATIONS

Under the direction of the Publication Committee there have been issued twelve numbers of The Journal with approximately 2461 pages of text and 638 pages of advertising matter; and Volume 31 of the Transactions. The Year Book is now issued but once a year and combines the geographical and alphabetical lists formerly issued in January and July.

Fred R. Low has been appointed a member of the Publication Committee to serve the unexpired term of H. W. Spangler, resigned.

HOUSE COMMITTEE

The House Committee have completed the decoration of the rooms of the Society, including the Secretary's office. These improvements have received favorable comments from the members and others. The Society's rooms are now especially inviting and comfortable and offer a convenient place for making appointments.

LIBRARY

The Society has received 218 gifts of books during the year, 176 by purchase and 85 by exchange. By the coöperation of Founder Societies in the administration of the libraries of the three Founder Societies as one library and extending the benefits, it is hoped that in the near future a trained engineer and librarian may be engaged, looking also to possible coöperation with the New York Public Library when it moves to the new site near the Society headquarters.

MEETINGS

Meetings of the Society are now being conducted in four cities. The Committee on Meetings having extended the privileges of the membership in Boston and St. Louis, have arranged for meetings of the Society in the cities of San Francisco and New York which shall be uniform with the first-mentioned cities.

During the past year there have been held seven meetings in New York with an average attendance of 271; in St. Louis six meetings with an average attendance of 75; and in Boston six meetings, with an average attendance of 240, some of these in coöperation with other societies. At the inauguration of meetings in San Francisco the Committee on Meetings delegated the Secretary of the Society and the Chairman of the Committee on Meetings to be in attendance. Past-President Jesse M. Smith and the Secretary also attended a meeting in St. Louis during the year.

Two new committees have been appointed, one on Meetings in New York, Walter Rautenstrauch, Chairman, Fredk. A. Waldron, Treasurer, F. H. Colvin, Edward Van Winkle and Roy. V. Wright, thus not only making all meetings uniform but also giving the nucleus of an organization to care for the social features of the regular Annual Meeting in New York. A Committee on Economic Administration of Industrial Establishments is being organized which shall have general responsibility for developing papers and meetings on that subject.

RESEARCH COMMITTEE

The Research Committee have prepared a list of laboratories of the various technical schools of the country. In addition to the name and location of the laboratory, the data include the name of the director, the field of engineering for which the laboratory is equipped, a list of subjects already investigated, the published reports, and a statement of problems under investigation. The Committee also have under consideration the development of a standard by which to judge the performance of safety valves.

STANDARD FLANGES

H. G. Stott, A. M. Mattice, J. P. Sparrow, and Wm. Schwanhausser have been appointed a committee to coöperate with the National Steam and Hot Water Fitters Association leading to the adoption of a uniform standard for flanged and screwed cast-iron fittings.

IDENTIFICATION OF POWER HOUSE PIPING

The committee appointed to report on the subject of standardizing the pipe coloring for power houses, H. G. Stott, Chairman, H.

P. Norton, Wm. H. Bryan, I. E. Moultrop and J. T. Whittlesey, advised the appointing of a special committee on the subject to establish at the earliest possible date a standard system of coloring. The same committee has been re-appointed for this work.

LAND FUND COMMITTEE

On the resignation of the former Land Fund Committee, a new committee was appointed by the Council, Worcester R. Warner, Chairman, C. N. Lauer, I. E. Moultrop, Geo. A. Orrok, F. H. Stillman. An active campaign has been started to clear the indebtedness of the Society for its share in the land on which the Engineering Societies Building rests, and $88,920.03 have been received to date, leaving $85,765.03 to be raised.

FINANCE COMMITTEE

The Finance Committee have taken an active oversight of the financial affairs of the Society and too much credit cannot be given for their conscientious work.

On account of the fact that election to membership occurs at a different date from that of the beginning of the fiscal year, at the request of the Council the question of partial dues has been considered carefully, with the result that amendments have been adopted during the year and have become a working basis, as shown in the report of the Committee on Constitution and By-Laws.

CONSTITUTION AND BY-LAWS

Under the direction of the Committee on Constitution and By-Laws, the following amendments have been made to the Constitution, By-Laws and Rules:

C 10 An Associate shall be thirty years of age or over. He must have been so connected with some branch of engineering or science, or the arts, or industries, that the Council will consider him qualified to coöperate with engineers in the advancement of professional knowledge.

C 11 A Junior shall be twenty-one years of age or over. He must have had such engineering experience as will enable him to fill a responsible subordinate position in engineering work, or he must be a graduate of an engineering school. A person who is over thirty years of age shall not be eligible to membership in the Society as a Junior.

C 45 The Standing Committees of the Society to be appointed by the President shall be:

Finance Committee.
Committee on Meetings.
Publication Committee.
Membership Committee.
Library Committee.
House Committee.
Research Committee.
Public Relations Committee.

B 11 Each person elected to membership, except an Honorary Member, must subscribe to the Constitution, By-Laws, and Rules of the Society, and pay the initiation fee before he can receive a certificate of membership in the Society. Resignations from membership shall be presented to the Council for action.

B 16 The initiation fee and the annual dues for the first year shall be due and payable on the first day of the month following the date of the election of a Member, Associate or Junior. The annual dues for each ensuing year shall be due and payable in advance on the corresponding day in each year thereafter. Upon the payment of the initiation fee and the annual dues for the first year, the person elected shall be entitled to the rights and privileges of membership in the grade to which he was elected. The date of payment of a member's annual dues may be changed to the first day of any other month, and a pro rata adjustment of the dues made, by application to the Secretary.

B 17 A Member, Associate or Junior in arrears for dues for one year, on the first day of October previous to the Annual Meeting, shall not be entitled to vote, or to receive the Transactions or the publications issued by the Society thereafter until such dues have been paid. Should the arrears for dues or otherwise be for more than two years, the name of such person shall be presented to the Council for such action as it deems advisable under C 24. Should the right to vote, or to receive the publications of the Society be questioned, the books of the Society shall be conclusive evidence.

B 18 The Council may, in its discretion, restore to membership any person dropped from the rolls for non-payment of dues, or otherwise, upon such terms and conditions as it may at the time deem best for the interests of the Society.

B 22 The Finance Committee shall consist of five Members or Associates. The term of office of one Member of the Committee shall expire at the end of each Annual Meeting. This Committee shall, under the direction of the Council, have a supervision of the financial affairs of the society, including the books of account. The Committee may cause the accounts of the Society to be audited and approved annually by a chartered or other competent public accountant. The Committee shall hold monthly meetings for the audit of bills and such other business as shall come before it and shall deliver to the Secretary for representation to the Council at the end of each fiscal year, a

report of the financial condition of the Society for the past year, and also shall present therewith a detailed estimate for the probable income and expenditure of the Secretary for the following twelve months. It shall make recommendations to the Council as to investments, and when called upon by the Council, advise upon financial questions. It shall have charge of the making of all contracts and other obligations to pay money in the Society's work and the ordering of all expenditures thereunder.

B 24 The Publication Committee shall consist of five Members or Associates. The term of office of one Member shall expire at the end of each Annual Meeting. The Committee shall review all papers and discussions which have been presented at the meetings, and shall decide what papers and discussions, or parts of the same, shall be printed in the Transactions of the Society. The Committee shall have the supervision of the monthly publication of the Society known as "The Journal." The Committee will be expected to publish all such data as will be of assistance to engineers or investigators in their work. At the end of each fiscal year the Committee shall deliver to the Secretary for presentation to the Council a detailed report of its work.

B 37 The Annual Meeting shall begin in the City of New York on the first Tuesday in December and continue from day to day as the Council may direct.

The Annual Business Meeting of the Society shall be held on the Wednesday following the first Tuesday of December.

The Semi-Annual Meeting shall be held in such a place and begin on such a day as the Council may direct, and continue from day to day.

The Semi-Annual Business Meeting of the Society shall be held immediately preceding the first professional session of the Semi-Annual Meeting.

Professional meetings of the Society for the reading and discussion of papers and for topical discussions may be held at such times and places as the Council may direct.

Announcements of all meetings of the Society shall be published in The Journal.

A notice of each Annual and Semi-Annual Meeting and each Annual and Semi-Annual Business Meeting of the Society shall be mailed by the Secretary to each member in each grade not less than 30 days before the date of that meeting and at least 30 days before each Special Business Meeting.

R 24 Engineers and others not members of the American Society, but desiring to participate in the meeting of the Section, may enroll themselves as affiliates as heretofore provided with the approval of the Executive Committee of the Section. Such affiliates shall have the privilege of presenting papers and taking part in the discussions. They shall pay $5 per annum which shall be due and payable in advance, on October 1 of each year of their enrollment, and shall thereby be entitled to receive the regular issues of The Journal for a period covered by their dues.

R 29 The American Society of Mechanical Engineers will furnish monthly issues of The Journal to all members of affiliated organizations who are not members of The American Society of Mechanical Engineers upon the pay-

ment by each of two dollars per year, such payment being due January 1 of each year. The American Society of Mechanical Engineers will furnish gratis to each affiliated body, extra copies of advance papers for use at its meetings, the number furnished to be agreed upon at the discretion of the Secretary.

R 35 The tellers of election in counting the ballots for officers shall consider the ballot for an officer as valid, provided the intent of the voter as to that particular office is clear, even though his ballot as to candidates for another office may for any reason be invalid.

A special committee appointed to report on improvements in the methods of balloting now in use in the Society, Theodore Stebbins, Chairman, W. T. Donnelly and Chas. E. Lucke, have made a report which is to be considered at a joint meeting of the committees interested.

MEETING IN ENGLAND

The Secretary and Honorary Secretary presented reports of the enjoyable trip to England and the meeting with The Institution of Mechanical Engineers. The former report is in narrative form while the latter treats of the significance of international meetings.

REPORT OF THE FINANCE COMMITTEE

After one of the most active years in the history of the Society your Committee is gratified in being able to present a financial report which indicates growth and prosperity financially as well as technically.

Although the current expenses of the Society were larger than in any time in its history, yet as will be seen from the appended reports the current income has met the expenses in full and has enabled us to cancel in this one year all of the extraordinary expenses up to date, due to the meeting with The Institution of Mechanical Engineers in England the past summer, and also to add to our surplus account. This has been made possible from the fact that our excess of income over expenses for the year was $10,649.41.

It is also interesting to note that at the close of the fiscal year our entire surplus represented by property and accounts receivable was $6433.56 greater than September 30, 1909.

The Committee regret to record that no specific results have been attained during the year just closed in the direction of reducing our mortgaged indebtedness. The total amount received during the past year to the credit of the land fund was not the equivalent of one-

fifth of the interest on the mortgage, thereby making it necessary to look elsewhere to meet this interest charge.

It seems to the Committee that there is an urgent necessity for a strong effort to reduce this mortgaged indebtedness materially each year until it is wiped out, and the interest money thereby is made available for the extension of our Society work.

Herewith are given the detailed statements of the financial condition of the Society, together with the reports of Peirce, Struss & Company, of New York, certified public accountants, who have audited the books and accounts, and also a statement of the condition of the various trust funds for the fiscal year.

PEIRCE, STRUSS & CO.
CERTIFIED PUBLIC ACCOUNTANTS
37 Wall Street, New York

October 26, 1910

MR. ARTHUR M. WAITT,
CHAIRMAN FINANCE COMMITTEE
Dear Sir:

In accordance with your instructions, we have audited the books and accounts of The American Society of Mechanical Engineers for the year ended September 30, 1910.

The results of this examination are presented in three exhibits, attached hereto, as follows:

Exhibit A Balance Sheet, September 30, 1910
Exhibit B Income and Expenses for the year ended September 30, 1910.
Exhibit C Receipts and Disbursements for year ended September 30, 1910.

We beg to present, attached hereto, our Certificate to the aforesaid exhibits.

Respectfully submitted,
PEIRCE, STRUSS & CO.
Certified Public Accountants

PEIRCE, STRUSS & CO.
CERTIFIED PUBLIC ACCOUNTANTS
37 Wall Street, New York

October 26, 1910

MR. ARTHUR M. WAITT,
CHAIRMAN FINANCE COMMITTEE
Dear Sir:

Having audited the books and accounts of The American Society of Mechanical Engineers for the year ended September 30, 1910, we hereby certify that the accompanying Balance Sheet is a true exhibit of its financial condition as of September 30, 1910, and that the attached statements of Income and Expenses, and Cash Receipts and Disbursements are correct.

PEIRCE, STRUSS & CO.
Certified Public Accountants

EXHIBIT A

BALANCE SHEET, SEPTEMBER 30, 1910

ASSETS

Equity in Societies Building (25 to 33 West 39th Street)	$353 346.62	
Equity one-third cost of land (25 to 33 West 39th Street)	180 000.00	
		$533 346.62
Library Books	13 000.00	
Furniture and Fixtures	5 000.00	
		18 000.00
New York City 3½% Bonds 1954 Par $35,000	30 925.00	
Cash in Bank representing Trust Funds	11 356.59	
		42 281.59
Stores including plates and finished publications		11 623.03
Cash in Bank for general purposes	3 611.73	
Petty Cash on hand	250.00	
		3 861.73
Accounts Receivable		
Membership dues	9 554.50	
Initiation fees	540.00	
Sale of publications, advertising, etc	6 360.04	
		16 454.54
Advances account of land subscription fund		9 955.22
Advanced payments		1829.65
Total Assets		$637 352.38

LIABILITIES

United Engineering Society (for cost of land)		$81 000.00
Funds		
Life Membership Fund	$35 151.07	
Library Development Fund	4 902.71	
Weeks Legacy Fund	1 957.00	
Land Fund Subscriptions	223.88	
Subscriptions to Annual Meeting	46.93	
		42 281.59
Current Accounts Payable		2 652.33
Membership dues paid in advance	804.25	
Initiation fees paid in advance	75.00	
		879.25
Initiation fees uncollected		540.00
Appropriation available to complete Vol. 31 of Transactions		4 200.00
Reserve (Initiation fees)		27 926.97
Surplus in property and accounts receivable		477 872.24
Total Liabilities		$637 352.38

EXHIBIT B

Income and Expenses for the Year Ended September 30, 1910

INCOME

Membership dues		$ 57 551.79	
Sales gross receipts		9 210.25	
Advertising receipts		24 230.26	
Interest and Discount		1 684.01	
			$92 676.31

EXPENSES

Finance Committee Office Administration including Salaries	$20 205.68		
Finance, United Engineering Society Assessments	4 500.00		
Finance, Miscellaneous	634.36		
		$25 340.04	
Membership Committee		2 350.49	
Increase of Membership Committee		2.70	
§House Committee			1 089.16
Library Committee			2 491.46
Meetings Committee			
Annual Meeting	2 394.40		
Spring Meeting	2 028.72		
Monthly Meetings	3 416.92		
London Meeting	2 270.23		
		$10 110.27	
Publication Committee			
Advertising Section, The Journal	11 791.32		
Journal, except Advertising	18 527.88		
Year Book	2 748.73		
Revises	131.96		
Transactions Vol. 31	2 801.79		
		$36 001.68	
		$77 385.80	
Research Committee		100.76	
Thurston Memorial Committee		139.06	
Sales Expenditures		4 401.28	
Total			$82 026.90
*Excess of Income over Expenses			10 649.41
			$92 676.31

§From Current Income $1 089.16
Reserve Fund 3 000.00
Total Expenses $4 089.16

*Of this amount $4200.00 is reserved to complete Vol. 31 of Transactions.

EXHIBIT C

Receipts and Disbursements for Year Ended September 30, 1910

RECEIPTS

Membership dues	$49 888.25	
Initiation fees	6 345.00	
Membership dues and initiation fees paid in advance	948.00	
Sales of publications, badges, advertising, etc.	31 733.56	
Subscriptions to Land Fund	616.00	
Subscriptions to Expense of Annual Meeting	360.20	
Interest	2 168.23	
	$92 059.24	
Cash in Banks and on hand, September 30, 1909	20 613.22	
		$112 672.46

DISBURSEMENTS

Disbursements for general purpose	94 214.14	
Interest on Mortgage on Land	3 240.00	
	97 454.14	
Cash in Banks and on hand, September 30, 1910	15 218.32	
		$112 672.46

Land Fund

RECEIPTS

Subscription	$71 662.76
Interest	573.56
Advances from Society	9 955.22
Property, 12 W. 31st St	63 000.00
	$145 191.54

DISBURSEMENTS

Acquisition of property	7 971.11	
Mortgage	99 000.00	
Interest	27 766.92	
Furnishings and equipment	7 671.81	
Occupancy building, moving library	2 171.06	
Expenses of Committee	386.76	
Cash on hand	223.88	
		$223.88
	145 191.54	

Cash on hand	223.88	
To be raised	90 731.34	
	90 955.22	
Amount of mortgage	81 000.00	
Advances by Society	9 955.22	
	90 955.22	

Life Membership Fund

Number of Life Members	90	
Number of Life Associates	6	
Number of Life Juniors	1	
	97	
97 Members at $15 = $1455		
4 per cent interest on $35,151.07 and credited to unappropriated revenue	$1 406.04	
Amount Oct. 1, 1910	35 151.07	35 151.07

Library Development Fund

Amount Oct. 1, 1909	4 902.71	
Balance Oct. 9, 1910		4 902.71

Weeks Legacy

Amount Oct. 1, 1909	1 957.00	
Balance Oct. 1, 1910		1 957.00

Thurston Memorial Fund

Subscriptions	788.32	
Interest	36.47	
Current Income 1909–1910	139.06	
	963.85	
Expenditures		
Bronze Memorial	850.00	
Reflector bracket	30.00	
Booklet	32.04	
Committee expenses	51.85	
	963.85	

Annual Meeting Subscription

Balance in the hands of the Local Committee and held by the Society in trust		46.93
		$42 281.59

The Committee also submit herewith as called for by the By-Laws a detailed estimate of the probable income and expenditure of the Society for the ensuing fiscal year:

ESTIMATE OF INCOME 1910-1911

Dues	$57 525
Sales, gross receipts	5 000
Interest and discount	475
Advertising	25 500
	$88 500

ESTIMATE OF EXPENSES 1910-1911

	FROM CURRENT INCOME	FROM RESERVE
Finance Committee	$28 740	
Membership Committee	2 450	
Increase Membership Committee	500	
House Committee	600	$ 400
Library Committee	4 500	
Meetings Committee	9 000	
Publication Committee	36 400	*1 500
Research Committee	300	
Public Relations Committee	100	
Committee on Power Tests	300	
Sales Expenditure	3 000	
Reserve Fund	600	
	$86 490	$1 900

Respectfully submitted,

ARTHUR M. WAITT, *Chairman*
R. M. DIXON
E. F. SCHNUCK
W. M. MARSHALL
G. W. ROBERTS
Finance Committee

REPORT OF THE HOUSE COMMITTEE

Your Committee during the year has completed the work embodied in the decorative scheme outlined in its last report. This included the tinting of the walls and the furnishing of new carpets, new

*Advanced on account meeting in England to be paid out of current income.

draperies and new furniture in the entrance hall, Council room and library. It is felt that these rooms now present an attractive, quiet and dignified appearance appropriate to the home of the Society.

Your Committee also acquired a uniform series of photographs of all the Past-Presidents, which are now hung upon the walls of the library.

Your Committee has in mind the extension of its original program with a view to unifying the plan of decoration in such of the rooms as are open to the general public, and hopes to carry out these plans during the coming year.

Your committee further proposes to secure photographs of the Honorary Members, to be framed in conformity with the photographs of the Past-Presidents already hung upon the walls.

Respectfully submitted,

WILLIAM C. DICKERMAN, *Chairman*
BERNARD V. SWENSON
FRANCIS BLOSSOM
EDWARD VAN WINKLE
H. R. COBLEIGH
} *House Committee*

REPORT OF THE LIBRARY COMMITTEE

No radical changes have been effected in the library organization during the past administration year.

The libraries of the three Founder Societies are being operated in parallel, the actual library work being handled jointly by the library staff and the administration of the libraries being conducted under an informal Library Conference Committee consisting of the chairmen of the library committees of the Founder Societies.

It is expected that more intimate relationships between the libraries will be established in the near future.

It is also expected that the United Engineering Societies' library will be organized and that gifts of libraries and books may be received by it where they are not made a specific donation to the library of one of the Founder Societies.

The number of visitors accommodated at the library shows a continued increase as indicated by the following tabulations:

	Day	Night	Total
July	609	Closed	609
August	560	Closed	560
September	596	261	857
	1765	261	2026
Night	261		
Total	2026		

	1908		1909		1910	
	Day	Night	Day	Night	Day	Night
January	541	148	485	250	460	286
February	439	241	533	254	416	232
March	417	203	535	280	439	256
April	403	210	529	217	488	274
May	400	196	462	221	454	279
June	419	136	484	198	471	239
July	441	closed	472	closed	609	closed
August	362	closed	472	closed	560	closed
September	393	125	434	220	596	261
October	381	180	471	238		
November	435	200	479	223		
December	520	441	545	301		
	5151	2080	5901	2402	4493	1827

Membership cards received:

American Institute Electrical Engineers	10
American Society Mechanical Engineers	8
American Institute Mining Engineers	20
Non-members	8
	46

As an indication of the range of subjects called for by visitors to the library and the relative frequency of consultation, the following table may be of interest, covering the months of April–September 1910:

	Apr.	May	June	July	Aug.	Sept.
Architecture	1	2	1		1	1
Bibliography						2
Biography	1				1	1
Chemical Technology	4	5	4	2	3	1
Chemistry	4	4	2	1	2	2
Civil Engineering	7	1	5	2	2	5
Description and Travel	1	1	1	1		
Electrical Engineering	17	12	22	6	20	14

	Apr.	May	June	July	Aug.	Sept.
Electricity	2	9	1	5	5	1
Engineering (General)	5	6	14	5	10	10
Geology	22	9	10	7	24	20
Hydraulic Engineering	2	3	4	2		10
Mathematics	5		1	1		9
Marine Engineering						
Mechanical Engineering	27	23	26	13	16	19
Metallurgy	14	4	11	13	4	1
Mining Engineering	16	11	20	9	9	6
Miscellaneous	1		3	4	1	4
Periodicals	49	28	89	30	39	90
Physics	7	2	2	3		7
Railroad Engineering		5		1		5
Railroad Engineering (Electrical)	1					7
	196	125	216	105	137	215

It has been felt that the appropriation available for the purchase of new books is inadequate to keep the library supplied with the latest books of reference.

The amount expended for books and periodicals in 1908 was $527.76. An approximately similar amount will be expended during the current year and your Committee in presenting its request for the appropriations for next year has submitted a request that the appropriation under this head be increased to $1500.

Your Committee has in preparation a book plate for the Society's library which will be submitted for the approval of the Council of the Society at an early date.

Respectfully submitted,

J. W. Lieb, Jr., *Chairman*
Ambrose Swasey
Leonard Waldo
Chas. L. Clarke
Alfred Noble

Library Committee

REPORT OF THE COMMITTEE ON MEETINGS

In addition to the Annual and Spring Meetings of the Society, 18 meetings have been held, six being held in each of the cities of New York, Boston and St. Louis. During 1911 meetings will also be held in San Francisco. At a number of these meetings sister societies and local engineering organizations coöperated, but the number of meetings given does not include those of other societies in which we coöperated.

It is the policy of your committee to meet weekly, excepting during the summer months, and including special meetings the Committee has practically carried out this policy during the period mentioned.

Fifty-four papers and three topical discussions have been accepted and published in The Journal, all of which have been or will come before meetings of the Society. These include eight papers presented at the meetings held at Birmingham and London.

Several cities other than New York, Boston, St. Louis and San Francisco are contemplating holding meetings, but they have not as yet reached a definite conclusion.

It has been suggested that appropriations be assigned for meetings, based on the number of members accessible to a locality. For the present, however, your Committee believes that the Society should do all possible to assist the membership in different localities in which these meetings are being held, to the limit of the available funds.

Your Committee finds that the local conditions vary at the different points and therefore repeats the suggestion contained in its report to the Executive Committee of May 31, 1910, that after more extensive experience of all the local committees on meetings has been obtained, they, in coöperation with the Committee on Meetings, formulate such rules as may be found necessary to establish uniformity in the conduct of all local meetings, the same to be subject to the approval of the Council.

A meeting of the local members in New York was held October 31, 1910, for the recommendation of names for a local committee, that New York City may be organized on the same basis as all other localities. It is intended that this committee, by the selection of some 20 assistants, shall also act as the entertainment committee for the Annual Meeting.

Your Committee has felt for some time that the papers presented before the Society have not been sufficiently diversified. It believes that it has overcome this to some extent, but with the further object of making the Transactions of the Society a more complete record of mechanical engineering progress, a circular has been mailed to the membership calling their attention to this point, which it is believed will result in materially increasing the value of the Transactions of the Society as a record of engineering progress. The attention given the circular so far is most gratifying and the membership is to be congratulated upon the interest it has inspired.

The rapid growth of industrial establishments has developed a

phase of mechanical engineering—that of economic administration—which your Committee feels should be given the attention by the Society that its importance warrants. This branch of the profession has evolved the administrative engineer until a very large percentage of the profession and of our membership is now occupying administrative positions in industrial establishments. Your Committee has had this question under attention for some time, but until recently it did not feel that the opportune time for definite action had arrived.

At its meeting, October 7, 1910, it requested the endorsement by the Council of the appointment of a sub-committee on the Economic Administration of Industrial Establishments. The committee is glad to have the Council's approval of its request and believes the field covered by this sub-committee can be made one of the greatest factors in our economic welfare.

Permit the Committee again to call the Council's attention to the recommendation that it feels the best interests of the Society would be subserved by a closer working arrangement between the Research Committee and the Committee on Meetings.

The Committee begs to thank the officers of the Society and the members of the office staff for the coöperation and assistance it has received.

Respectfully submitted,

WILLIS E. HALL, *Chairman*
WM. H. BRYAN
L. R. POMEROY
CHAS. E. LUCKE
H. DE B. PARSONS

Meetings Committee

REPORT OF THE MEMBERSHIP COMMITTEE

During the current year the Membership Committee has held six meetings, at which the total of 337 applications for membership have been considered with the following results:

Withdrawn for various causes	14
Deferred indefinitely	17
Recommended for membership	306

Of the 306 names recommended for ballot 276 were candidates for new membership and 30 were candidates for promotion. The candidates recommended were voted for on two ballots submitted to the membership as follows:

Spring ballot..... 159
Fall ballot..... 147

The small number of names deferred and the fact that no objections have been received to the names placed upon the professional service sheets testifies to the increasing care taken by the members in filling out the application blanks, and to the careful manner in which all cases are studied in the Secretary's office before being submitted to the committee. The Committee, however, would emphasize again that its work will be greatly facilitated and the standards of the Society safeguarded if members will agree to act as proposers and seconders of an applicant only when they can support the latter through personal knowledge of his work.

The Committee desires to report that the new rules regarding the Junior and the Associate membership grades put into effect at the Spring Meeting, have operated upon the whole in a very satisfactory manner, and in the judgment of the Committee have placed the classes of membership upon a basis that makes for the best interests of the Society.

The Committee would recommend that it be given authority to prepare a list of approved engineering schools that will be used to interpret the phrase "engineering schools" in clause C 11 of the Constitution relating to the admission of Junior members.

Respectfully submitted,

C. R. RICHARDS, *Chairman*
GEORGE J. FORAN
THEODORE STEBBINS
FRANCIS H. STILLMAN
HOSEA WEBSTER
} *Membership Committee*

REPORT OF THE PUBLICATION COMMITTEE

The Committee has had to meet the constantly growing number and length of papers presented to the Society by the members at its annual and monthly meetings by a very careful elimination or condensation of everything which might be termed extraneous or superfluous in order to keep within the confines of a single volume of the Transactions.

Volume 31, for 1909, just issued, contains 1069 pages and the current Volume 32 embracing, in addition to the Society papers the papers presented at the English meeting, will contain between 1500 and 2000 pages. This would be considered the outside limit of size.

The largest volume heretofore printed was No. 24 for 1903 which contained 1563 pages and was thought unwieldy, and yet if the growth of our available matter continues at anything like its present rate, we will be confronted with the necessity of binding the Transactions in volumes of about this size. An alternative would be the omission of the printing of the Transactions altogether as such, thereby avoiding the duplication of 75 per cent of the reading matter of The Journal.

This would be done by printing in The Journal previous to meetings a list only of the papers which will be read at the meeting, requesting members who desire to discuss any particular paper to send for a copy of it. After the meeting, The Journal would publish all papers with all discussions and at the end of the year would supply binders in which all copies of The Journal may be bound. This volume would continue the present series of the Transactions. By this means the papers would be printed once only instead of twice and the annual saving to the Society would be approximately $5000, which could be applied to making the Library more accessible to members.

Previous to this year, The Journal has been published monthly, except in July and August when there were no issues, and in October and November to accommodate the additional amount of matter necessitated by the Annual Meeting it has appeared semi-monthly. This year, however, the arrangement has been changed so as to have it appear monthly throughout the year.

The gross and net cost of issuing the Society publications is given in the following tables for each of the past five fiscal years ending September 30.

EXPENDITURES

	1906–1907	1907–1908	1908–1909	1909–1910	1910–1911
History		$ 95.06	43.65		
Revised papers		182.56	523.93	131.96	300
Year Book and Pocket List	2 232.35	2 622.57	3 000.89	2 748.73	3 200
Transactions	8 400.20	6 100.00	6 533.87	7 001.79*	8 600
The Journal	11 487.98	8 425.58	20 160.86	30 319.20	25 800
	22 120.53	17 425.77	30 263.20	40 201.68†	37 900

INCOME

Advertising			11 997.50	24 227.26	25 500
Appropriations	22 120.53	17 425.77	18 265.70	15 974.42	12 400

* Approximate.
† Estimated.

It will be seen that the net cost to the Society is gradually being lessened; the slight increase for 1908–1909 being due to the change in the issue of both the Year Book and the Pocket List to a combination of the two in one.

There has never been a complete cross-reference index of the Transactions, and there has been for a long time a crying need for one. Recently the Library Committee has had in mind the indexing of the Transactions of all the societies and it will be necessary to carry out a complete indexing of our Transactions in this connection. The Committee is now in conference with the Library Committee on the best method of coöperation in this work.

Respectfully submitted,

D. S. JACOBUS, *Chairman*
H. F. J. PORTER
FRED R. LOW
GEO. I. ROCKWOOD
GEO. M. BASFORD
Publication Committee

REPORT OF THE RESEARCH COMMITTEE

The last formal meeting of the Research Committee was held December 10, 1909. At that meeting it was agreed that it would be unwise for the Committee to enter at once upon the investigation of problems of research. It was agreed that as a preliminary to actual work there should be on file in the office of the Secretary, a complete list of the college, commercial and other laboratories of the country, the organization of which might permit them to do work in line with the purposes of our Society. In addition to the name and the location of the laboratory, it was proposed to have the name and address of its director and a statement concerning the extent of its staff and equipment, also a list of the subjects which have been investigated and a reference as to where the reports thereof may be found, a statement of the problems now under investigation, and a statement of the field of engineering for which the laboratories are especially equipped. The circulars which have been sent out have been worded so as to make it clear that the Committee does not wish to intrude itself upon the activities of any laboratory, but that the inquiry grows out of a desire on the part of the representatives of a national organization to know how thoroughly the field is now covered. The responsibility for sending out these circulars and for tabulating the information obtained was left with the Secretary of the Society.

It is the understanding of your Committee that the work of gathering this information is now practically complete, and that there is on record in the Secretary's office all information along this line.

It was also agreed that the Committee might properly undertake a research concerning the performance of safety valves, and a circular has been issued designed to develop the most important facts which should be determined concerning the action of such valves. These were sent to 68 safety-valve manufacturers, to 125 railroads of 100 miles or over, and to three large boiler manufacturers. Forty-one replies have been received. Eighteen have no information regarding pop safety valves. Nine of the replies are of especial interest and have been abstracted as follows:

The Consolidated Safety Valve Company refers to Mr. Philip Darling's paper before the Society in 1909 and to experiments of Professor Miller of the Massachusetts Institute of Technology. They favor a high lift for steam passage. As to the rating of the various sizes they favor the continuation and duplication of the Darling and Miller tests. Nickel bronze is favored for valve seats and copper bronze with 10 per cent tin for valves. To maintain efficiency they favor keeping the exhaust steam away from the spring, and exposure to air currents for cooling. They consider the aperture has little effect on the capacity but is an important element of the lift. They suggest experiments to develop the effect of temperature and of steady loads and rapidly varying loads, on springs, also a study of the various rules governing sizes and design of various supervising authorities with the aim of developing a safe and uniform rule, applicable to all sizes. They suggest that many common faults of safety valves be made the subject of reports in boiler inspection service. Railroads which have a system of report covering engine failures might also outline the most common troubles with safety valves.

The Ashton Valve Company refers to the tests of Professor Miller, of the Massachusetts Institute of Technology. They favor the low lift from a practical standpoint with 30 years experience. They suggest tests determining a proper rating of safety-valve boiler based on the capacity of relief that the valve should give. They favor high grade composition of bronze metal made of copper and tin about 8 to 1. Regarding efficiency they make outside spring valve with spring free from steam exposure for use where steam temperature is over 400 deg. fahr. As to aperture bevel seat valves 45 deg. angle give best results. Regarding additional facts they express the opinion that it will be difficult to establish a rule adaptable to both stationary and locomotive boilers and they discuss this point at length.

Crane Company know of no reliable data regarding discharge but refer to A. J. Hewling's discussion, in The Journal, Am. Soc. M. E., June 1909. They are willing to submit valves and take part in public tests in order that reliable data may be had. They favor high grade composition of valve and valve seats and state that they have no experience of springs losing temper. Facts about the effect of the shape of the apertures have led them to adopt a cushion disc and spring which allows the highest lift practicable. As to tests they

suggest that the committee provide accommodations where safety valves may be tested under the same conditions and under most careful observation.

The Lunkenheimer Company do not know of any accurate data other than manufacturers' tests. They favor a lift of $\frac{1}{16}$ in. to $\frac{1}{64}$ in. They suggest time tests to determine the efficiency and lift of valves with various lifts under a wide range of actual service conditions and pressures. They favor nickel bronze composition, high percentage of nickel for the seat and a high grade steam metal for the disc. The outside spring type of valve is used to avoid undue heat and to maintain the efficiency. As to the shape of the aperture, they suggest six points to be considered. For research they suggest the evolution of a simple and practical rule for determining sizes based on a moderate constant lift.

Crosby Steam Gage and Valve Company have submitted a reply of some thirty pages accompanied by illustrations and catalogues. For data they refer to the Annual Report of the U. S. Steamboat Inspectors, 1877; thesis of Bardsley and Miller, Case School of Applied Science, 1906, data of tests referred to in Steam Boilers by Professor Peabody, p. 240; and tests now being made at Massachusetts Institute of Technology, 1910. Regarding the lift in safety valves they cite the experience of manufacturers' measurements at factories and in actual service; measurements made at the Massachusetts Institute of Technology, 1909. They suggest fixing standard or limits of lift, to insure durability of valves; measuring discharge of various designs of valves at same fixed lifts; reporting minimum lift and discharge which have been ample in past; and defining characteristics of operation most desirable in safety valves. They favor bronze composition, high percentage of tin, low in zinc and lead; nickel composition not to be endorsed. Exposing springs outside of valve body involves friction; encasing spring in inner chamber involves sticking; long spindles, large valve casings, well drained spring chambers essential without sliding contacts. Regarding open shape of aperture, see tests of Massachusetts Institute of Technology in "Steam Boilers" by Professor Peabody; also tests in progress at Massachusetts Institute of Technology, 1910; also Kent's Pocketbook, p. 724. For research they suggest verbal explanation in detail of essential characteristics of design of each valve as made; of the general principles involved, and defense of engineering reasons, advantages and objections governing each detail; in other words, the engineering "confession of faith" of each manufacturer and his own exegesis of each article of it.

Rock Island Lines: W. A. Nettleton knows of no boiler being blown up because the safety valve fails to properly relieve. Statistics of Mr. Curtis of the Master Mechanics Association Committee indicate very few boilers explode from over pressure, the majority explode from low water, due generally to carelessness. This applies to locomotive service in which the boiler is very closely watched. As to the durability, a number of small valves are preferable to a very large one. He is skeptical regarding the tendency towards a higher lift. He has had no experience as to temper of the spring and steam. He assumes the spring loses elasticity because of repeated strains.

Canadian Pacific Railway Company: Mr. Vaughan, Vice-President, considers it desirable to investigate for flat seats and V-shaped seats the amount of steam flowing per hour with different heights of lift, the height to which valves now in use lift with given increments of pressure, the effect of various forms of coupling devices based on the pressure between the seat of the valve

and the muffler; so as to obtain data on which to base a specification providing that a given diameter should have a lift of not less than a certain amount with a given increment of pressure between the seat of the valve, that there should be not more than a certain amount of pressure between the seat and the muffling device, that the area through the muffling device should bear a certain proportion to the area of the valve.

Babcock and Wilcox Company: Mr. F. A. Scheffler refers to the formula on p. 9, 1910 catalogue of the Consolidated Safety Valve Company, based on valves having 45 deg. beveled seat and actual evaporation tests. He states that complete data can be obtained from this company and also from the Naval Experimental Station, Annapolis, Md. He favors composition seats having at least 25 per cent nickel. Regarding deterioration, he states that a well-designed spring of good quality spring steel should not lose temper under saturated steam, and that an exposed spring design should be used under superheated steam. Very complete information has been published by the Consolidated Safety Valve Company in their book entitled Safety Valve Capacity.

Heine Safety Boiler Company: Col. E. D. Meier writes that experimental data are mainly in the possession of various firms and companies which manufacture high class valves, and cites the Consolidated Company, the Ashcroft Company and the Ashton Company, who have recently installed a boiler suitable for 400 lb. pressure for continuing such experiments. He states that the rules promulgated by various officials and societies seem to be based on experiments made at lower pressure than current practice. These rules may be deficient because action of metals under higher stresses and higher temperature will be different than in the early experiments. Mr. Geo. H. Musgrave has had some experience as a pioneer and is an enthusiast on the subject. There is great need of experimental work and the only safe way for a scientific settlement of these questions would be tests on entirely neutral grounds, i.e., in the laboratory of some well equipped mechanical engineering school of high repute. His company has to conform to three different rules: the regulations of the Board of Supervising Inspectors of Steam Vessels; the Philadelphia Boiler Law; the Boiler Rules of Massachusetts. They give different dimensions so designers are guided by the locality where the boiler is to be operated. An important question is the limit in size, that is, when it becomes necessary to put two or even three safety valves on a boiler in place of one. The amount of lift has a bearing on this.

It may be deduced from the above correspondence that what is needed in determining a method of rating valves is not so much research as it is standardization of practice, defined by recommendations having the weight of the Society behind them. For example, the testimony seems to show that valves having low lift and high lift are operative, and that advocates of both are to be found among people well qualified to pass opinions on the operation of valves in service. It may be that lift is a factor which, while hitherto regarded as of importance, may be neglected, and that its effect will be entirely absorbed in any arrangement which will secure a rating of valves in

accordance with their discharge capacity. This and other general questions which have been developed by its inquiry will be considered at a formal meeting of the Committee to be held at the time of the next Annual Meeting of the Society, at which time it should be possible to take the next step in the development of the Committee's work.

Respectfully submitted,

W. F. M. Goss, *Chairman*
R. C. Carpenter
R. H. Rice
Ralph D. Mershon
Jas. Christie

Research Committee

of the books whose first editions appeared in the years 1882 to 1894 inclusive:

The Materials of Engineering. 3 vol. I, Non-metallic Materials; II, Iron and Steel; III, Brasses, Bronzes and other Alloys.
A Text Book of Materials of Construction.
Treatise on Friction and Lost Work in Machinery and Millwork.
Manual of Steam Boilers, their Design, Construction and Operation.
Handbook of Engine and Boiler Trials, the Indicator and the Prony Brake.
Translation of Sadi-Carnot's "Reflections on the Motive Power of Heat and on Machines fitted to Develop that Power."
Life of Robert Fulton.
Manual of the Steam Engine. 2 vol. I, History, Structure and Theory; II, Design, Construction and Operation.
Stationary Steam Engines, Simple and Compound.
The Animal as a Machine and Prime Motor, and the Laws of Energetics.

Many of these books ran through several editions; the second volume of Materials of Engineering, Iron and Steel, is now in its ninth, and the Treatise on Friction and Lost Work, the Manual of Steam Boilers, and Stationary Steam Engines, are each in their seventh edition. The work of revising these books to keep them up to date was no small labor, and several of them have as many as four copyright dates. The Manual of the Steam Engine, and the Handbook of Engine and Boiler Trials, have been translated into French.

Most of these books are severely technical and of interest only to engineers and engineering students; but two of them, the translation of Carnot's little book and The Animal as a Machine, appeal also to those interested in advanced physics. He translated Carnot not because he thought the book would sell, but, as he says in his preface, "as a matter of limited but most intense scientific interest," and he compliments the publishers for their undertaking to print the book without any prospect of financial return. Yet in seven years a second edition was printed. Dr. Thurston's appreciation of Carnot in the introduction is a good example of his literary style when writing on non-technical subjects.

Nicholas-Leonard-Sadi-Carnot was perhaps the greatest genius in the department of physical science that this century has produced. By this I mean that he possessed in the highest degree that combination of the imaginative faculty with intellectual acuteness, great logical power and capacity for learning, classifying and organizing in their proper relations all the facts, phenomena and laws of natural science, which distinguishes the real genius from other men

and even from simply talented men. Only now and then in the centuries does such a man come into view. Euclid was such in mathematics, Newton was such in mechanics, Bacon and Comte were such in logic and philosophy, Lavoisier and Davy were such in chemistry, and Fourier, Thomson, Maxwell, and Clausius were such in mathematical physics. Among engineers we have the examples of Watt as inventor and philosopher, and Rankine as his mathematical complement, developing the theory of that art of which Watt illustrated the practical side.

But Carnot exhibited that most marked characteristic of real genius, the power of applying such qualities as I have just enumerated to great purposes and with great result while still a youth. Genius is not dependent, as is talent, upon the ripening and the growth of years for its prescience; it is ready at the earliest maturity, and sometimes earlier, to exhibit its marvelous works; as for example note Hamilton, the mathematician, and Mill, the logician, the one becoming master of a dozen languages when hardly more than as many years of age, reading Newton's Principia at sixteen, and conceiving that wonderful system, quaternions, at eighteen; the other competent to begin the study of Greek at three, learning Latin at seven, and reading Plato before he was eight. Carnot had done his grandest work of the century in his province of thought and had passed into the Unseen at 36; his one little volume, which has made him immortal, was written when he was but 23 or 24.

A fine example of Dr. Thurston's grasp of a subject of scientific thought beyond the domain of engineering, and even beyond the present borderland of physics, is seen in the following brief extract from The Animal as a Machine:

The living body is a machine in which the law of Carnot, which asserts the necessity of waste in all thermodynamic processes and in every heat engine, and which shows that waste to be the greater as the range of temperature worked through by the machine is the more restricted, is evaded; it produces electricity without intermediate conversions and losses; it obtains heat without high temperature combustion; and in some cases light without any sensible heat. In other words, in the vital system of man and of the lower animals, nature shows us the practicability of converting any one form of energy into any other, without those losses and unavoidable wastes characteristic of the methods, the invention of which has been the pride and the boast of man. Every living creature, man and worm alike, shows him that his task is but half accomplished; that his grandest inventions are but crude and remote imitations; that his best work is wasteful and awkward. Every animate creature is a machine of enormously higher efficiency as a dynamic engine than his most elaborate constructions. Every gymnotus living in the mud in a tropical stream puts to shame man's best effort in the production of electricity; and the minute insect that flashes across his lawn on a summer evening, or the worm that lights his path in the garden, exhibits a system of illumination incomparably superior to his most perfect electric lights . . . Here is Nature's challenge to man. Man wastes one-fourth of all his fuel as utilized in his steam boiler, and often 90 per cent as used in his fireplace; nature in the animal system utilizes substantially all.

Dr. Thurston was an occasional contributor to such journals as the Popular Science Monthly, the Forum, Science, and the North American Review. Sometimes he went outside of the field of the physical sciences and wrote on sociological and economic subjects, such as the tariff. Once he wrote for the North American Review a statement of his religious convictions.

He frequently wrote papers and delivered addresses on educational subjects, and in these he was naturally at his best. For nearly forty years he was an educator and an educational leader. He was versed in the theories of Froebel, Milton and Comenius; and of Spencer, John Scott Russell and other modern writers. His paper on Technical Education in the United States; its Social, Industrial and Economic Relations to our Progress, read at the International Engineering Congress at Chicago in 1893, is one of his masterpieces. It is a calm, scholarlike review of the conditions of the past, and a hopeful view of the future. He propounded no new theories, he originated no new fads, but he was in line with the best thinkers of his time, and thoroughly in sympathy with the modern trend toward industrial or trade education for the great mass of the people.

DR. THURSTON AT SIBLEY COLLEGE, CORNELL UNIVERSITY

By Walter C. Kerr

Member of the Society; Trustee of Cornell University

What a man is, makes less difference to the world than what his life teaches; the man departs, but his teaching remains. It would be impossible for me to relate here the full importance of the eighteen years that Dr. Thurston devoted to Cornell University. Prior to 1885 Cornell was developing a department of mechanic arts in a small way, recognizing the necessity and opportunities of mechanical engineering. With a profitable sale of the university's timber lands the trustees felt warranted in taking forward steps, chief among which was the founding of a new department, and to this department of mechanical engineering Dr. Thurston was called as the first director. No choice was ever more fortunate. I will not undertake to recount all that followed in physical development from his administration, except to say that the number of students increased from one hundred to eleven hundred, buildings grew, facilities grew, everything that his hand touched grew, and all the growth was healthy. Professor

Thurston was especially an organizer, and of the very best kind This was because he knew what to organize. His methods were direc and practical, he knew men, he understood human nature; and al resistance was to him merely a retardation, not a stopping, and conse quently he gained whatever he set out to do.

By temperament, education and experience he was peculiarly fitted to direct socially and intellectually an important department i a complex institution; by his touch with all the forces of life he wa an important factor in any community in which he lived, and thi gave him a profound and wide influence for good through a mucl larger circle than that of engineering. He convinced men, by per suading them to want what he wanted, and the result was that h usually gained his end with the minimum of argument. His ever present cheerfulness was an inspiration, and his patience was a example. There is no subtle mystery about why he was so love and respected at Cornell, nor why he accomplished so much. Hi ways were ways of peace, and his achievements were a series o creative victories. He was a strong man, so strong that we hono his memory tonight. He has gone, but the influence of his life lives

No. 1275

TEST OF A 15,000-KW. STEAM-ENGINE-TURBINE UNIT

H. G. Stott, New York
Member of the Society

R. J. S. Pigott,[1] New York
Non-Member

During the year 1908 it became apparent that owing to the fast increasing traffic in the New York subway, it would be necessary to have additional power available for the winter of 1909–1910.

2 The power plant of the Interborough Rapid Transit Company, which supplies the subway, is located on the block bounded by 58th and 59th Streets, and by 11th and 12th Avenues, adjacent to the North River; it contains nine 7500-kw. (maximum rating) engine units, besides three 1250-kw. 60-cycle turbine units which are used exclusively for lighting and signal purposes.

3 The 7500-kw. units consist of Manhattan-type compound Corliss engines, having two 42-in. horizontal high-pressure cylinders and two 86-in. vertical low-pressure cylinders. Each horizontal high-pressure cylinder and vertical low-pressure cylinder has its connecting rod attached to the same crank, so that the unit becomes a four-cylinder 60-in. stroke compound engine with an overhanging crank on each side of a 7500-kw. (maximum rating), 11,000-volt, three-phase, 25-cycle generator. The generator revolving field is built up of riveted steel plates of sufficient weight to act as a flywheel for the two engines connected to it. This arrangement gives a very compact two-bearing unit. The valve gear on the high-pressure cylinders is of the poppet type, and on the low-pressure of the Corliss double-ported type.

4 The condensing apparatus consists of barometric condensers,

[1] Asst. Supt. Motive Power, Interborough Rapid Transit Company.

Presented at the New York meeting, March 1910, of The American Society of Mechanical Engineers.

arranged so as to be attached directly to the low-pressure exhaust nozzles, with the usual compound displacement circulating pump and simple dry-vacuum pump.

5 These engine and generator units are in general probably the most satisfactory large units ever built, as five years' experience with them has proved. Their normal economic rating is 5000 kw., but they operate equally well (water rate excepted) on 8000 kw. continuously.

6 In considering the problem of how to get an additional supply of power, every available source was considered, but by a process of elimination only two distinct plans were left in the field.

7 The electric transmission of power from a hydraulic plant was first considered, but owing to the high cost of a double transmission line from the nearest available water power, and the impossibility of getting reliable service (that is, service having a maximum total interruption of not more than ten minutes per annum) from such a line, further consideration of this plan was abandoned.

8 The gas engine, while offering the highest thermodynamic efficiency, at the same time required an investment of at least 35 per cent more than an ordinary steam-turbine plant, with a probable maintenance and operation account of from four to ten times that of the steam turbine.

9 The reciprocating-engine unit of the same type as those already installed, was rejected in spite of its most satisfactory performance, on account of the high first cost and small range of economical operation. Reference to Fig. 5, Series A, will show that the economic limits of operation are between 3300 kw. and 6300 kw.; beyond these limits the water rate rises so rapidly as to make operation undesirable under this condition, except for a short period during peak loads.

10 The choice was thus narrowed down to either the high-pressure steam turbine or the low-pressure steam turbine. There was sufficient space in the present building to accommodate three 7500-kw. units of the high-pressure type, or a low-pressure unit of the same size on each of the nine engines, so that the questions of real estate and building were eliminated from the problem.

11 The first cost of a low-pressure turbine unit is slightly lower than that of a high-pressure unit, due to the omission of the high-pressure stages and the hydraulic governing apparatus, but the cost of the condensing apparatus would be the same in both cases. The foundations and the steam piping in both cases would not differ greatly. The economic results, so far as the first cost is concerned, would then be approximately the same, if we consider the general

case only; but in this particular instance the installation of high-pressure turbines would have meant a much greater investment for foundations, flooring, switchboard apparatus, steam piping and water tunnels, amounting to an addition of not less than twenty-five per cent to the first cost.

12 The general case of displacing reciprocating engines and installing steam-turbine units in their place was also considered. The best type of high-pressure turbine plant has a thermal efficiency approximately 10 per cent better than the best reciprocating-engine plant, but the items of labor for operation and for maintenance, together with the saving of about 85 per cent of the water for boiler-feed purposes and the 10 per cent of coal, reduce the relative operating and maintenance charges for the steam-turbine plant to 80 per cent, as compared with 100 per cent for the reciprocating-engine plant.

13 Assuming that the reciprocating engine plant is a first-class one and has been well maintained, about 20 per cent of its original cost (for engines, generators and condensers) may be realized on the old plant and so credited to the cost of the high-pressure turbine plant. But on the other hand, if the high-pressure turbine installation is to receive credit for the second-hand value of the engines, it must also have a debit charge for 100 per cent of the original reciprocating-engine plant which it displaced. The relative investments, therefore, upon this basis would be approximately equal for the high-pressure or the low-pressure turbine; but 80 per cent of the cost of the original engine plant would have to be charged against the high-pressure turbine plant, as against an actual increase in value (to the owner) of the engine by reason of its improved thermal efficiency due to the addition of the low-pressure turbine.

14 The preliminary calculations, based upon the manufacturers' guarantees for the low-pressure and high-pressure turbines showed that the combined engine-turbine unit would give at least 8 per cent better efficiency than the high-pressure turbine unit, so that it was finally decided to place an order for one 7500-kw. (maximum rating) unit, as by this means we would not only get an increase of 100 per cent in capacity, but at the same time give the engines a new lease of life by bringing them up to a thermal efficiency higher than that attained by any other type of steam plant.

15 The turbine installed (Fig. 1) is of the vertical three-stage impulse type, having six fixed nozzles and six which can be operated by hand, so as to control the back pressure on the engine, or the division of load between engine and turbine. An emergency overspeed governor,

which trips a 40-in. butterfly valve on the steam pipe connecting the separator and the turbine and at the same time the 8-in. vacuum

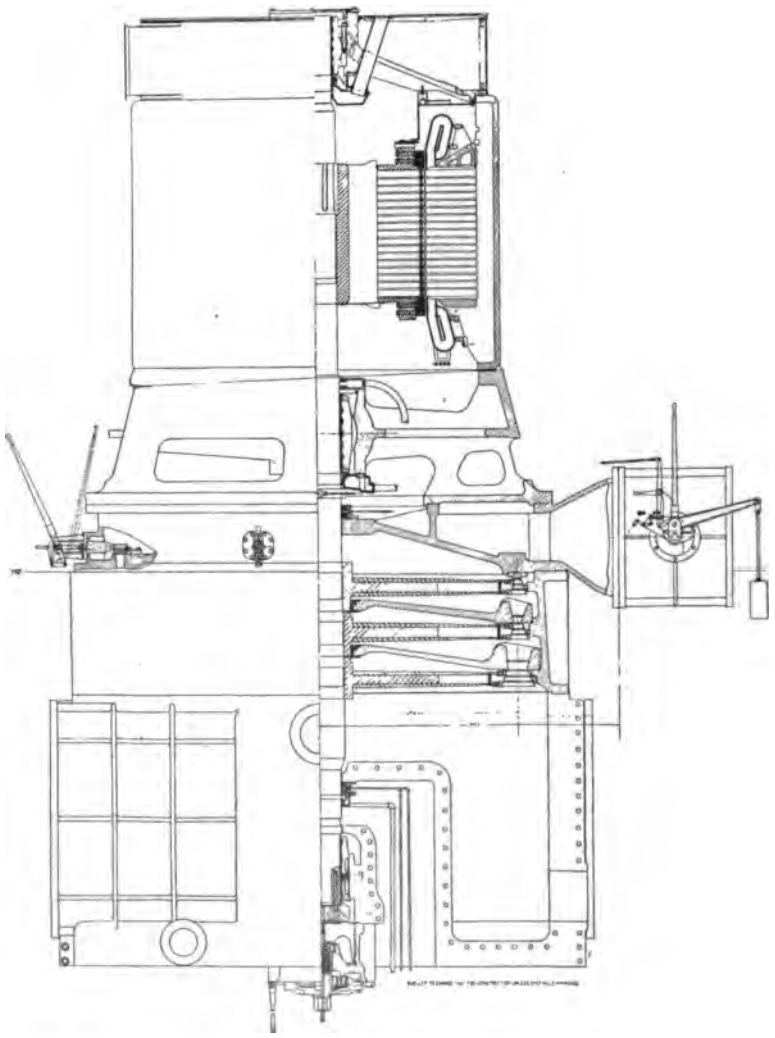


FIG. 1 ELEVATION AND PART SECTION OF LOW-PRESSURE TURBINE UNIT

breaker on the condenser, is the only form of governor used. The footstep bearing, carrying the weight of the turbine and generator rotors, is of the usual design supplied with oil under a pressure of

600 lb. per sq., in. with the usual double system of supply and an accumulator to regulate the pressure and speed of the oil pumps.

16 The condenser contains approximately 25,000 sq. ft. of cooling surface arranged in the double two-pass system of water circulation, with a 30-in. centrifugal circulating pump having a maximum capacity of 30,000 gal. per hr. The dry vacuum pump is of the single-stage type, 12-in. and 29-in. by 24-in., fitted with Corliss valves on the air cylinder. The whole condensing plant is capable of maintaining a vacuum within 1.1 in of the barometer when condensing 150,000 lb. of steam per hr. when supplied with circulating water at 70 deg. fahr.

17 The electric generator is of the three-phase induction type, star-wound for 11,000 volts, 25 cycles and a speed of 750 r.p.m. The rotor is of the squirrel-cage type with bar winding connecting into common bus-bar straps at each end. This type of generator was chosen as being specially suited to the conditions obtaining in the plant.

18 With nine units operating in multiple, each one capable of giving out 15,000 kw. for a short time, operating in multiple with another plant of the same size, it is evident that it is quite possible to concentrate 270,000 kw. on a short circuit. If we proceed to add to this, synchronous turbine units of 7500-kw. capacity, which, owing to their inherently better regulation and enormous stored energy, are capable of giving out at least six times their maximum rated capacity, the situation might soon become dangerous, as it would be impossible to design switching apparatus which could successfully handle this amount of energy. The induction generator, on the other hand, is entirely dependent upon the synchronous apparatus for its excitation, and in case of a short circuit on the bus-bars would automatically lose its excitation by the fall in potential on the synchronous apparatus.

19 The absence of fields permits the simplest possible switching apparatus, as the induction generator leads are tied in solidly through knife switches, which are never opened, to the main generator leads. The switchboard operator has no control whatever over the induction generator, and only knows it is present by the increased output on the engine generator instruments.

20 The method of starting is simplicity itself—the exciting current is put on the engine generator *before* starting the engine, and then the engine is started, brought up to speed and synchronized in exactly the same way as before. While starting in this way, the induction

generator acts as a motor until sufficient steam passes through the engine to carry the turbine above synchronism, when it immediately becomes a generator and picks up the load. Three of these 7500-kw. low-pressure turbine units have been installed (see Figs. 2 and 3) and tests run on Nos. 1 and 2. No. 3, having been just started, has not yet been tested.

21 Instead of inserting in this paper the enormous accumulation of data incident to these tests, we added an Appendix to the paper in the hope that it would thus be more accessible for reference, the paper itself giving the reasons for adopting this particular type of apparatus, with a brief description of the plant and a summary of the results obtained; and the Appendix containing all the principal data acquired during the tests, with sufficient explanation to make their meaning clear without reference to the text.

22 The tables and curve sheets are as follows:

Series A: Engine tests made in connection with acceptance tests, and also later to determine best conditions for operation.

Series B: Calculations and data furnished by turbine manufacturer to determine probable results when combined with engine data obtained in Series A.

Series C: Tests on No. 1 combined unit. This unit was hurriedly put into commission in order to obtain results to determine future developments. To get the piping done, old riveted steel pipe was used which was very leaky under vacuum. Results are valuable however as showing the effect of vacuum on performance as compared to Series E and F. Quality of steam entering turbine also poor.

Series D: Tests of No. 2 unit, with poor vacuum and poor quality of steam entering turbine.

Series E and F: Tests on No. 2 combined unit; conditions of vacuum and quality of steam entering turbine nearly standard, so that corrections are small.

23 In all results, except where specially noted, moisture corrections are simple corrections, i. e., for each percentage of moisture only a one per cent correction has been made. Vacuum corrections for the combined unit are 1 lb. for each inch variation from 28.5 in. when referred to 29.92 in. barometer.

24 The first point which presents itself in view of the remarkable results of these tests, is the question of accuracy of measure-

FOLDER No. 1

FOLDER No. 2

ment. The actual unit water-rate is dependent upon three factors only: quality of steam entering the engine, kilowatt load, and weight of water per hour. The quality of high-pressure steam is easily and accurately determined by means of the ordinary throttling calorimeter. The load on the machines was determined by means of nine integrating meters: two meters each on turbine, engine and total load, connected by the 2-meter method; one balanced 3-phase meter each on turbine, engine, and total load. Each meter was calibrated once a week, and the error was always within one-half of 1 per cent.

25 The weight of water from the turbine hot-well was determined by a pair of 40,000-lb. standard platform scales, with a recording device in addition to the hand weighing. The load was about 25,000 lb. per scale, the limitation being the size of the tanks on the scales. These scales are graduated to 5 lb. and will balance to 2 or 3 lb., so that the error in reading is negligible. Receiver trap water and low-pressure separator water were weighed together on a pair of 2000-lb. platform scales, reading to ½ lb. All scales were calibrated with standard 50-lb. weights before testing.

26 The actual trap water weight was obtained by interposing a 1-in. Venturi meter with recording device in the line to the scales; this was also calibrated by scales and found correct to less than 1 per cent, and the low-pressure separator water obtained by difference.

27 For examination of thermodynamic conditions within the machines, the most important determination is that of the quality of low-pressure steam to the turbine, since on this depends one of the important corrections to guaranteed conditions. There were no experimental data available that we could discover, bearing on low-pressure quality determinations, so the investigation was made incidental to the tests, from which the following was established. The ordinary standard perforated pipe sampler is absolutely worthless in giving a true sample, and it is vital that the sample be abstracted from the main without changing its direction or velocity until it is safely in the sample pipe and entirely isolated from the rest of the steam. Multiple orifice nozzles are of no use, as in all cases one orifice will supply practically all the steam, leaving the others useless. After much experimenting with various styles of samples, all of which were failures, the single orifice curved tube (Fig. 4) was adopted.

28 The reason for failure of other styles is plain; if any sudden turn is made by the wet steam in entering the sample nozzle, the entrained moisture, by reason of its immensely greater specific gravity and slight skin friction in the tenuous surrounding fluid, will continue

with unchanged direction and a dry sample will enter the nozzle. In other words, the sampler becomes a very fair separator. Again, if the velocity in the sampler is greater than that in the main, even

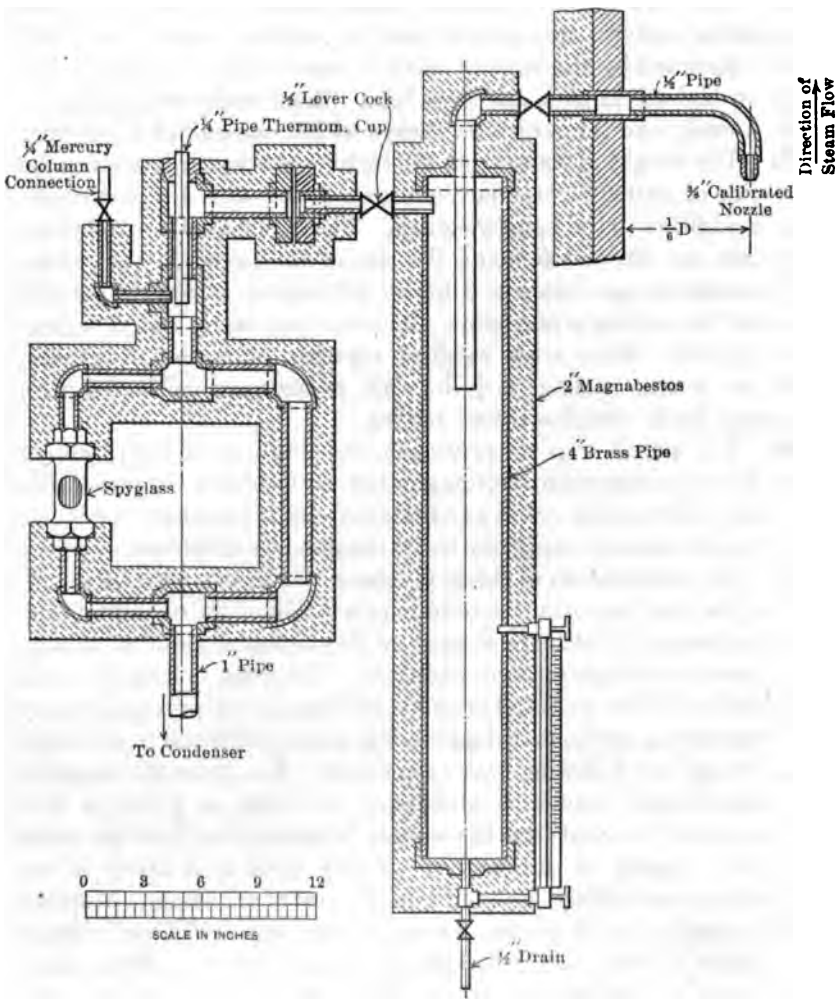


FIG. 4 LOW-PRESSURE SEPARATING-THROTTLING CALORIMETER

though there be no separating action with the proper sampler, the steam will accelerate into the nozzle, and the moisture will not, giving a dry sample; and the reverse is true if the velocity is less in the sam-

pling nozzle than in the main. The reason this very simple action has not been noted in connection with high-pressure steam is the smaller difference in specific gravity of water and steam, the enormously greater skin friction and the small percentage and highly-divided state of the moisture present.

29 The successful types of calorimeter for very wet steam were the Thomas electric, and a combination of a separating calorimeter with a throttling calorimeter (Fig. 4). By the use of the separating calorimeter most of the moisture was removed, and the small remainder was registered by the throttling calorimeter. At first glance it seems as if, with an initial pressure of 12 lb. to 20 lb. absolute, the throttling calorimeter has no capacity, but by putting a vacuum of 28 in. on the discharge side of the calorimeter, an available heat is obtained sufficient to evaporate 2 or 3 per cent of moisture. When the moisture became less than this, we used the throttling calorimeter direct, eliminating the separating calorimeter altogether. The separating-throttling combination was afterward tested for radiation loss and found to lose less than 0.1 per cent at proper flow. Fig. 4 shows this combination instrument. The large size is necessary on account of the very high specific volume of steam at low pressure.

30 Referring to Fig. 4, the $\frac{3}{8}$-in. brass nozzle on the sampler is arranged to point in exactly the opposite direction to the steam flow; the lip of the nozzle is filed to a knife-edge to avoid disturbing the steam current around the sampler mouth by impact and eddies against a sensibly thick lip. The diameter of the brass nozzle is carefully measured and, if necessary, reamed smooth. This form of sampler fulfills the requirements noted above; it takes out the sample without disturbing its direction, by virtue of its position and knife-edged orifice, and the velocity can be kept correct by determining the flow from the following simple formula:

$$w = \frac{Wa}{A}$$

where

w = lb. per hr. flow through calorimeter
W = lb. per hr. flow through steam main
a = area of sampler nozzle
A = area of main

The sampler is allowed to extend into the pipe one-sixth of the pipe diameter, which has been found to give practically true average flow.

31 The $\frac{1}{2}$-in. valve at the sampler is opened wide, and the $\frac{1}{2}$-in. lever cock between separating and throttling calorimeters is used to

regulate the flow, the throttling action taking place at this point. The rest of the calorimeter is under vacuum, the discharge being connected to a small cooler to condense the steam and then to a volumetric measuring tank. The top of this tank, which is entirely closed except for the pipe connections, was connected with the turbine condenser by a ½-in. pipe, which gave an available vacuum of over 28 in. without affecting the measuring in any way. The spy-glass is very useful in proving that the calorimeter is working properly, for when the superheat in the throttling calorimeter gets below 6 or 8 deg. it sometimes happens that some moisture goes by, in which case the spy-glass immediately shows it up, no matter how small the quantity. As the spy-glass is most conveniently made of ¾-in. gage glass, more area is required to take away the steam from the calorimeter, and this was done by adding a by-pass of 1-in. pipe around the spy-glass. This allows free flow to take place and does not affect the function of the glass.

32 The percentage of moisture taken out by the separating portion of the instrument divided by the total percentage of moisture gives the efficiency of the separating calorimeter, which turns out to be much lower than is ordinarily supposed, from 60 to 80 per cent.

33 For the rest of the measurements steam pressures throughout were taken with high-grade thermometers, graduated to 1 deg. and in many cases as low as 0.2 deg., as these are in every case preferable to gages for saturated steam. All pressures below 15 lb. gage and all vacua were measured by mercury column in addition to temperatures.

34 The net results obtained by the installation of low-pressure turbine units may be summarized as follows:

a An increase of 100 per cent in maximum capacity of plant.

b An increase of 146 per cent in economic capacity of plant.

c A saving of approximately 85 per cent of the condensed steam for return to the boilers.

d An average improvement in economy of 13 per cent over the best high-pressure turbine results.

e An average improvement in economy of 25 per cent (between the limits of 7000 kw. and 15,000 kw.)over the results obtained by the engine units alone.

f An average unit thermal efficiency between the limits of 6500 kw. and 15,500 kw. of 20.6 per cent.

APPENDIX

TABLES, DIAGRAMS AND FORMULAE

Table 1, Steam to Auxiliaries, includes for tests 25, 22, 24, 21, 23 and 26, the circulating water pump steam only; test 27, circulating water pump and dry vacuum pump; test 29, circulating water pump, dry vacuum pump and boiler feed pump; test 30, boiler feed pump alone.

Fig. 15 and Fig. 15a show variation of points is due to errors in earlier low-pressure calorimetry, before the standard instruments were settled upon.

Table 12, the column of unit water-rate total correction, is based on a standard vacuum of 28.72 in. instead of 28.5 in., as the higher figure was the average vacuum of the series of tests. Consequently the absolute amount of correction was reduced, which is of course very desirable, in view of the uncertainty of correction factors.

In Fig. 18 these water rates are uncorrected for moisture, etc.

In Fig. 36 the calorimeters were drawn for the sake of clearness as if they were situated at some distance from the sampling points; actually they were as in Fig. 5.

Figs. 37, 38 and 39 serve to show the variation in load between engine and turbine and the effect of change of efficiency of the two machines.

Formulae and Constants

Table I Engine Data

Two high-pressure cylinders 42 in. by 60 in., 9-in. rod
Two low-pressure cylinders 86 in. by 60 in., 10-in. rod
R.p.m. 75
Two 14-in. steam mains
Two 16-in. high-pressure exhausts
Two 30-in. low-pressure exhausts
Clearances
High-pressure head 9.5 per cent. Crank 10 per cent
Low-pressure head 4.77 per cent. Crank 4.78 per cent
Average total volume high pressure 51.7 cu. ft.
low-pressure 209.9 cu. ft.
Average displacement high pressure 47 cu. ft.
low-pressure 200.3 cu. ft.
I.h.p. constant. High pressure 15.38. Low pressure 65.57 (average).

All combined cards worked out on average basis. Marks and Davis tables used for steam data.

TABLE II

E_r = Rankine thermal efficiency, cyclic
E_t = Engine thermal efficiency
H_1 = Heat in initial steam at pressure p_1 quality x (total per hour)
H_2 = Heat in steam at p_2, x_2, after adiabatic expansion from p_1, x_1 (total hour)

$\frac{H_1 - H_2}{H_1} = E_r E_t = \frac{\text{kw.} \times 3412}{H_1}$ $\frac{E_t}{E_r} = E_e$ = engine efficiency referred Rankine cycle
No heat recovered

TABLE III

P_a, V_a = pressure and volume at high-pressure cut-off, lb. per sq. in. and ft.
P_c, V_c = pressure and volume at high-pressure compression
W_a = specific density at p_a
W_c = specific density at p_c
$V_a W_a - V_c W_c = W$, lb. indicated steam per stroke
$\frac{W \times 75 \times 4 \times 60}{\text{i.h.p}}$ = indicated water rate (i.w.r.)
i.w.r. $(1+y)$ = actual water rate (a.w.r.)
$y = 1.29\ (r - 1.06)$ kw. $\times$ 1.465 = i.h.p.
$r = \frac{51.7}{V_a}$ for high-pressure cycle = ratio of expansion

TABLE IV

Q_e = Total dry steam per hour to engine
Q_f = Trap water per hour
X_e = low-pressure exhaust quality
$(Q_e - Q_f)\ X_e$ = dry steam to turbine, Q_t

TABLES VI AND VII

X_t = quality of steam to turbine after passing separator
$1 - X_t = W$, wetness of steam to turbine after passing separator
K_e = engine kilowatt output
K_t = turbine kilowatt output
Q_e = dry steam to unit per hour
$\frac{Q_e}{K_e + K_t}$ = actual water rate W for unit
Q_f = trap water per hour
Q_s = separator water per hour
X_1 = high-pressure quality
$\frac{Q_e}{X_1} - Q_s - Q = Q_t'$
$Q_t'\ X_t = Q_t$
$\frac{Q_t}{K_t}$ = actual turbine water rate, W_t

$\frac{Q_e}{K_e}$ = actual engine water rate, W_e

$\frac{Q_e}{K_e + K_t\,(1+W)}$ = unit water rate, corrected for moisture in turbine steam, W

$W' - (28.5 - p'_2) = W''$ total corrected unit water rate

p'_2 = actual vacuum obtained, in mercury

Tables IX and X

All throttling calorimeters.

$X_1 = \frac{H_2 + K\,(T - t_2) - Q}{L}$ H_2 = total heat per lb. saturated steam at p_2. calorimeter discharge pressure

X_1 = quality

K = separator heat superheated steam at p_2, T

T = temperature superheated steam in calorimeter

All separating calorimeters.

$X_2 = \frac{W_f}{W_m + W_f}$ t_2 = temperature saturated steam at p_2

Q = heat per lb. of the liquid

L = latent heat vaporization per lb. at p_1

W_m = moisture

W_f = flow

All combustion separator-throttle calorimeters.

$X_1\,X_2 = X_1$ combined quality

Thomas electric calorimeter

$\frac{3.412E}{W} - K(T-t) = 1-X$

L

E = watt-hour input

W = lb. steam flow

K = as above

T = as above

t = saturated steam temperature at p

L = latent heat per lb. at p

X = as above

Table XII

See Tables VI and VII

Tables XIII, XIV

$E_t = \frac{\text{kw. } 3412}{H_1}$ for engine turbine or unit

$E_t' = \frac{\text{kw. } 3412}{X_1 - Q}$ for unit and turbine only

E_t = thermal efficiency no heat recovered

E_t' = thermal efficiency hot-well heat recovered

TABLE 1 SERIES A, ENGINE TESTS

Test No.	Engine Load, Kw.	Steam Pressure, Lb. Gage	Steam Temperature, Deg. Fahr.	Steam Superheat, Deg. Fahr.	Receiver Pressure (from Temp.), Lb. Gage	Vacuum Standard 29.92 In. Barometer, In. Mercury	Quality of Steam, Per Cent	Water per Hour, Lb.	Dry Steam per Hour, Lb.	Receiver Drain per Hour, Lb.	Steam to Auxiliary, Lb.	Injected Water Temp., Deg. Fahr.	Discharged Water Temp., Deg. Fahr.	I.h.p. High Pressure, H.p.	I.h.p. Low Pressure, H.p.	I.h.p. Total H.p.	Dry Steam per Kw-Hr., Lb.	Dry Steam per I.h.p.-Hr., Lb.
25	3100	180.1	388.3	9.7	9.13	28.81	100.55	56040	56349	2989	1517	36.8	55.7	2173	2306	4479	18.18	12.58
22	4008	176.7	383.9	5.7	16.87	27.99	100.32	68190	68407	4383	1866	38.4	58.3	2699	2815	5514	17.07	12.43
24	4977	174.4	387.8	10.6	21.7	28.00	100.58	85369	85865	5273	2949	36.8	65.3	3264	4076	7341	17.25	11.70
21	5984	173.9	387.5	10.5	25.9	28.00	100.60	103896	104519	6031	1699	37.73	69.5	3717	4714	8431	17.47	12.40
23	6772	173.3	385.5	8.7	30.0	27.71	100.50	124702	125326	6060	2091	37.7	70.4	4346	5732	10078	18.51	12.37
27	4992	173.9	387.3	10.5	10.44	28.11	100.60	89525	90063	5367	1826	37.76	72.66	3770	5184	6954	18.04	12.95
26	4970	173.2	386.1	9.4	15.21	28.00	100.53	86267	86724	5518	1728	35.9	61.1	3443	3452	6895	17.45	12.58
29	4976	174.9	386.9	9.4	20.41	28.00	100.53	85557	86010	5294	3034	38.1	75.0	3124	3722	6846	17.29	12.50
28	4970	174.3	388.8	11.7	25.35	28.02	100.66	85933	86501	4890	663	36.7	72.6	2982	4127	7109	17.42	12.17
31	3998	177.7	387.5	8.9	32.62	....	100.51	109317	109874	5948	....	....	....	2625	2372	4997	27.55	21.90
32	4980	176.2	386.7	8.7	36.93	....	100.50	128056	128695	6352	....	....	....	2835	3333	6168	25.84	20.85
30	4961	148.2	372.0	7.0	21.06	28.04	100.40	86041	86394	5082	1284	37.46	72.4	3068	4019	7087	17.82	12.48

TABLE 2 SERIES A

Test No.	Engine Load, Kw.	B.t.u. added per Lb. Water	B.t.u. Rejected per Lb. Water	Eff. Rankine, Per Cent	Eff. Thermal, Per Cent	Eff$_T$ / Eff$_R$ Per Cent	B.t.u. Drains, Per Cent	B.t.u. Construction and Radiation Loss, Per Cent	B.t.u. Mech. Elec. Loss, Per Cent	Remarks
25	3100	1205	840	30.3	15.7	51.7	0.9	71.4	12.0	
23	4008	1202	865	28.0	16.7	59.6	1.3	70.0	12.0	
24	4977	1204	866	28.1	16.5	58.1	1.2	70.3	12.0	
21	5984	1204	866	27.1	16.3	58.2	1.1	70.6	12.0	
23	6772	1203	875	28.3	15.4	56.4	1.0	71.6	12.0	
27	4992	1205	865	28.2	15.8	56.0	1.0	71.2	12.0	
26	4970	1204	866	28.1	16.3	58.1	1.2	70.5	12.0	
29	4976	1205	866	28.1	16.4	58.6	1.2	70.4	12.0	
26	4970	1206	866	28.2	16.4	58.1	1.1	70.5	12 0	
31	3988	1205	1017	15.6	10.3	66.2	1.1	76.6	12.0	Non-condensing
32	4980	1204	1017	15.5	11.0	71.1	1.0	76.0	12.0	Non-condensing
30	4961	1200	875	27.1	16.0	59.7	1.1	70.9	12.0	

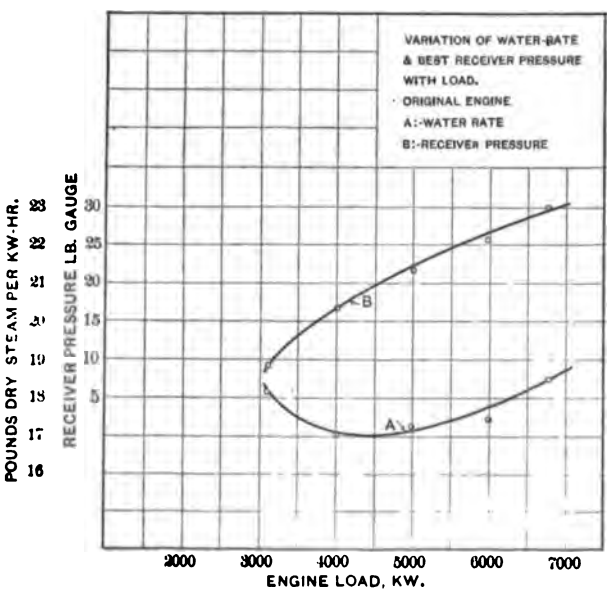


FIG. 5 SERIES A

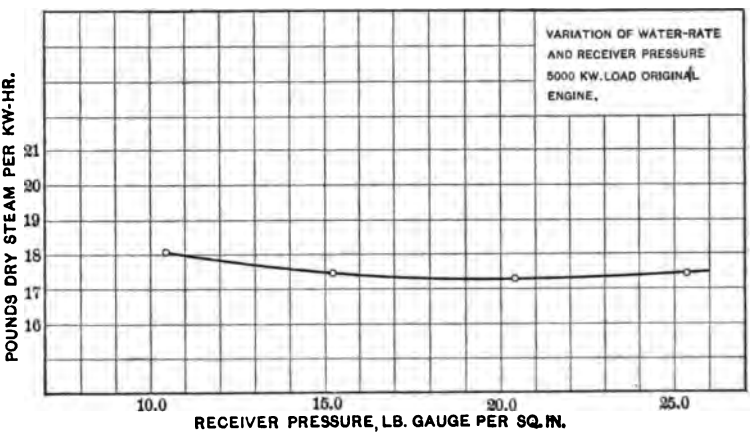


FIG. 6 SERIES A

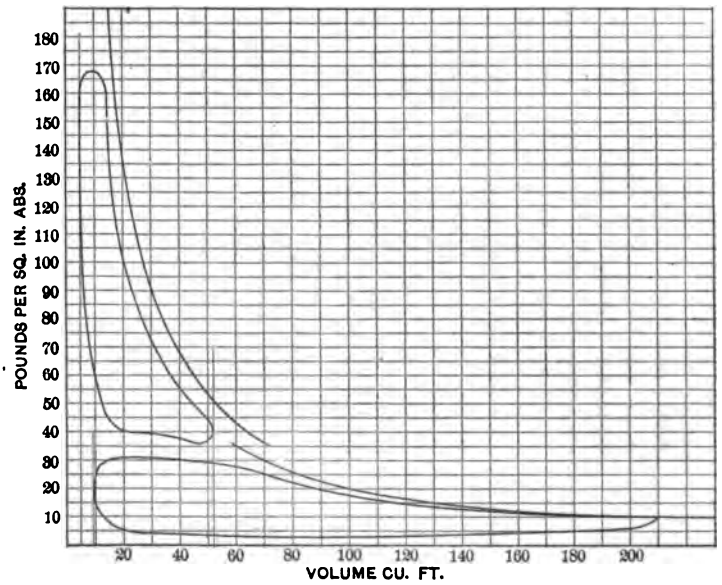


FIG. 7 SERIES A, TEST 29

TABLE 3 SERIES B

Test No.	Load, Kw.	I.h.p.	Ratio High Press. / Low Press. I.h.p.	P_a Lb. per Sq. In. Abs.	P_c Lb. per Sq. In. Abs.	V_a Cu. Ft.	V_c Cu. Ft.	W_a Lb. per Cu. Ft.	W_c Lb. per Cu. Ft.	Steam per Stroke High Press. Card, Lb.	r	y	Indicated Water Rate per I.h.p., Lb. per Hour	Actual Water Rate per I.h.p., Lb. per Hour	Actual Water Rate per Kw-Hr., Lb. per Hour	Receiver Press., Lb. per Sq. In. Abs.	Exhaust Press., Lb. per Sq. In. Abs.	Steam Press., Lb. per Sq. In. Abs.	Steam Press., Total Water, Lb. per Hour
25	3100	4479	0.943	137.32	66.12	10.78	7.56	0.3058	0 1544	2.131	4.80	0.469	8.57	12.59	18.18	19.8	0.9	191.5	56349
22	4008	5515	0.959	143.0	65.3	13.77	9.31	0.3176	0.1526	2.951	3.41	0.298	9.64	12.41	17.07	31.6	1.0	192.8	68407
29	4976	6846	0 840	142.4	73.8	16.64	9.30	0.3163	0.1709	3.670	3.11	0.302	9.65	12.56	17.29	36.4	1.0	190.9	86010
24	4977	7341	0.801	141.8	75.7	17.13	9.30	0.3151	0.1751	3.769	3.32	0.265	9.24	11.69	17.25	35.1	0.9	191.0	85865
21	5984	8431	0.789	141.8	74.1	21.48	9.29	0.3142	0.1716	5.154	2.42	0.128	11.00	12.40	17.47	40.6	0.9	191.0	104519
23	6772	10078	0.759	140.6	89.0	25.40	9.29	0.3126	0.2037	6.080	2.04	0.154	10.86	12.44	18.51	44.7	1.0	190.9	125326
31	2988	5900	1.403	143.7	72.2	19.83	7.56	0.3191	0.1675	5.058	3.11	0.206	15.43	18.62	27.55	47.3	14.7	192.2	109874
32	4981	7004	0.807	143.7	75.8	23.44	7.57	0.3191	0.1753	6.154	2.21	0.155	15.81	18.28	25.84	51.6	14.7	189.7	128695
Assumed cards, variable nozzle pressure																			
A	4050	5936	1 04	187.8	82.5	10.93	4 70	0.4107	0.1897	3.597	4.73	0.474	12.00	17.69	25.92	39.7	7.0	215	105000
B	5590	8192	1.05	182.2	96.0	16.45	4.70	0.3991	0.2186	5.537	3.14	0.268	12.18	15.45	22.63	46.0	10.0	215	126600
C	6710	9836	1.07	176.0	119.5	22.80	4.70	0.3862	0.2685	7.55	2.27	0.156	13.62	15.98	23.40	52.2	13.5	215	157300
D	7370	10792	1.10	168.6	122.8	29.83	4.70	0.3708	0.2753	9.71	1.73	0 087	16.30	17.72	25.95	58.5	18.0	215	191100
E	7740	11336	1 05	160.9	136.2	37.60	4.70	0.3549	0.3034	11.92	1.31	0.033	18.91	19.54	28.61	64.7	23.0	215	221400
Assumed cards, constant nozzle pressure																			
F	3875	5676	1.12	182.2	136.2	16.45	4.70	0.3991	0.3034	5.140	3.14	0.268	16.31	20.69	30.30	64.7	16.0	215	117400
G	5795	8484	0.988	176.0	136.2	22.80	4.70	0.3862	0.3034	7.374	2.27	0.156	15.57	18.00	26.38	64.7	16.0	215	152700
H	7190	10540	0.974	168.6	136 2	29.83	4.70	0.3708	0.3034	9.633	1.73	0.087	16.45	17.88	26.20	64.7	16.0	215	188500
I	8200	12008	0.938	160.9	136.2	37.60	4.70	0.3549	0.3034	11.92	1.31	0.033	17.86	18.45	27.04	64.7	16.0	215	221700

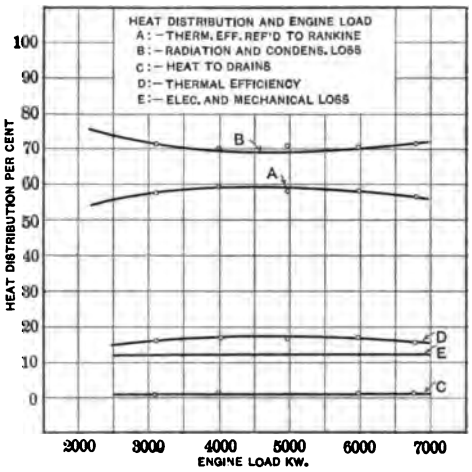


FIG. 7a SERIES A

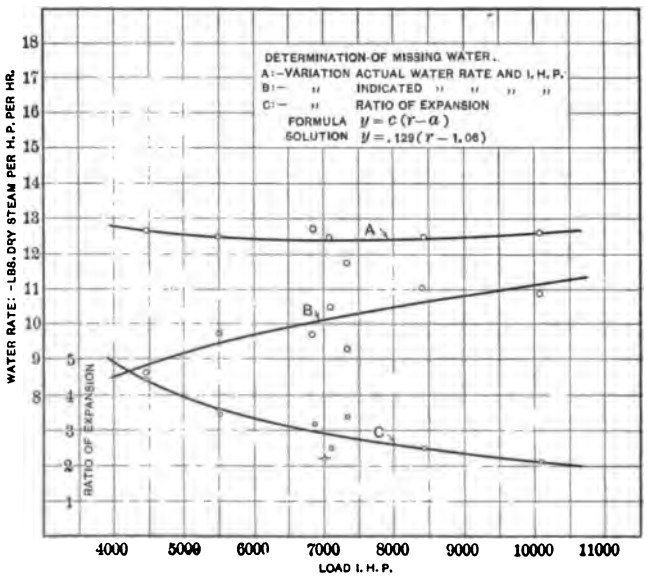


FIG. 8 SERIES B

TABLE 4 SERIES B.

ASSUMED CARDS LOW PRESSURE EXHAUST QUALITY DATA

Test No.	Water per Hour, Lb.	High Press. Steam to Low Press. Cylinders, Per Cent Moisture at Low Press., Admission, Per Cent	Admission Press., Lb. Per Sq. In. Abs.	Relief Press., Lb. Per Sq. In. Abs.	Exhaust Press., Lb. Per Sq. In. Abs.	r	Quality of Low Press. Exhaust, Per Cent	Comb. Quality, Per Cent	Dry Steam Turbine, Lb. Per Hour	
A	105000	93.2	37	9.5	.....	2.76	90.6	84.4	88600	Variable
B	126600	94.3	43	14	.....	2.47	90.9	85.7	108500	nozzle
C	157300	95.2	49	19	.....	2.26	91.4	86.9	136700	press.
D	191100	95.9	55	24	.....	2.10	91.6	87.8	167800	
E	221400	96.2	60	28	.....	1.98	91.9	88.4	195600	
F	117400	96.8	60	20	17.5	3.30	90.8	84.5	99200	Constant
G	152700	95.7	60	20	17.5	2.94	90.5	85.5	130600	nozzle
H	188500	94.4	60	23	17.5	2.46	90.8	86.9	163800	press.
I	221700	93.1	60	27	17.5	1.98	91.6	88.7	196600	

REMARKS AND FORMULAE

Tests 21-29 inclusive, 8 hr.

Tests 31-32, 8 hr. atmospheric exhaust non-condensing

$$\frac{\text{i.h.p.}}{\text{kw.}} = 1.465$$

$r = \frac{51.7}{V_b}$ for high-pressure card = ratio of expansion

$y = 0.129\,(r - 1.06)$ = missing water

w = specific density at p

$W_b \times V_b = W_1 \quad Wc \times Vc = W_2 \quad W_1 - W_2 = W_3$

$\frac{W_3 \times 60 \times 4 \times 75}{\text{i.h.p.}}$ = i.w.r. at high-pressure cut-off

i.w.r. $\times (1 + y)$ = a.w.r. per i.h.p-hr.

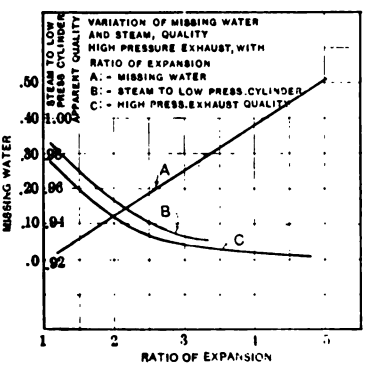


FIG. 9 SERIES B

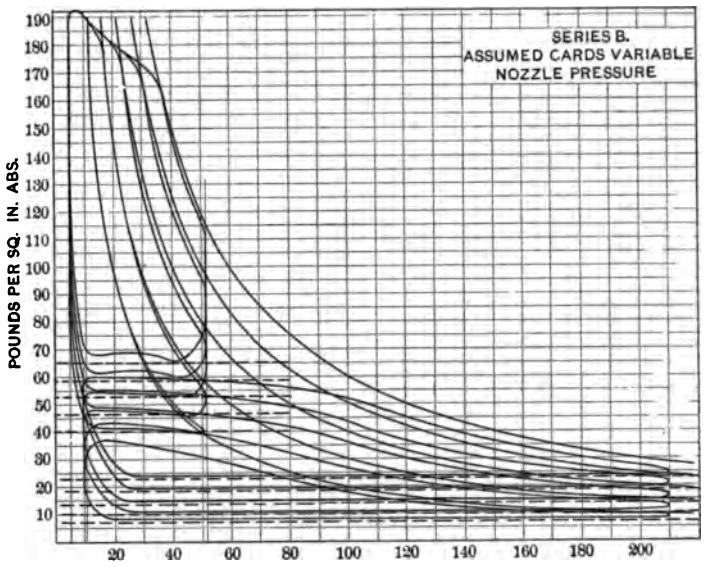


FIG. 10 SERIES B

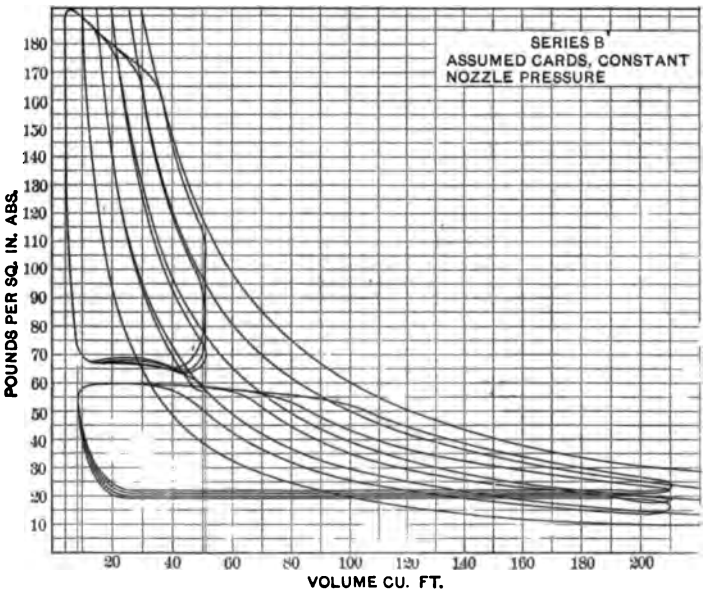


FIG. 11 SERIES B

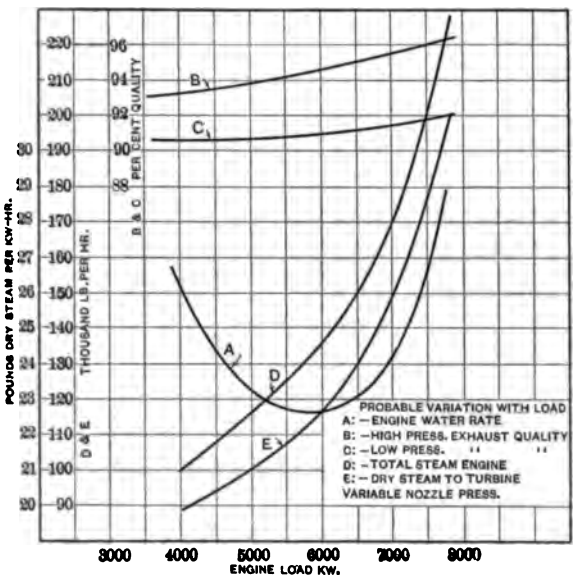


FIG. 12 SERIES B

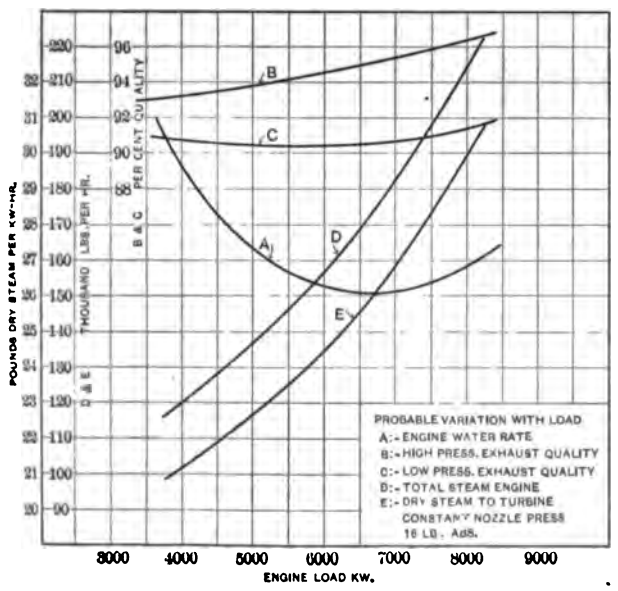


FIG. 13 SERIES B

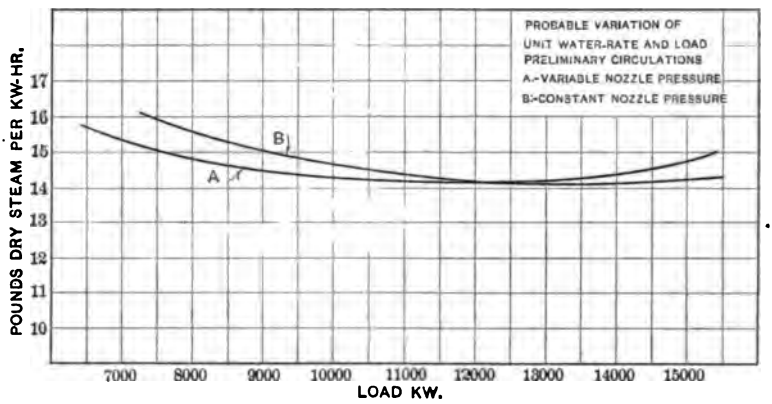


FIG. 14 SERIES B

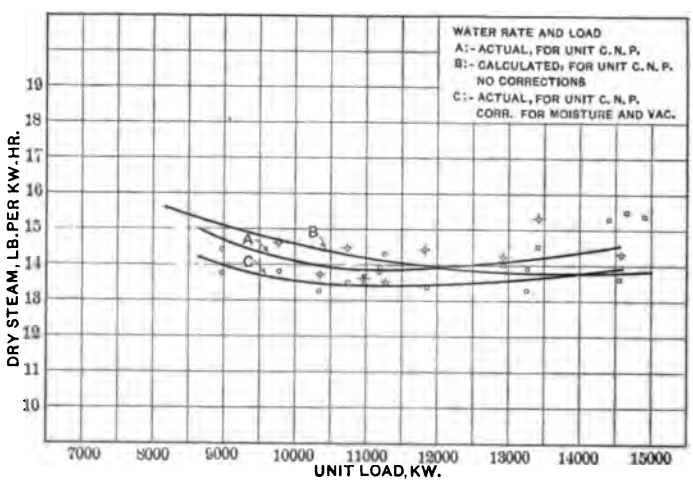


FIG. 15 SERIES C

Results of Observations Corrected to 29.92 In. Barometer and 14.7 Lb. Atmosphere

Test No.	Duration, Hours	Loads, KW.			Pressures					Qualities Per Cent		Water, Lb. Per Hour			Dry Steam, Lb. Per Hour		Temperatures, Deg. Fahr.		
		Unit	Engine	Turbine	High-Press. Steam, Lb. Gage per Sq. In.	Receivers, Lb. Gage per Sq. In.	Low-Press. Steam, Lb. Abs. per Sq. In.	Low-Press. Steam, Lb. Gage per Sq. In.	Vacuum, In. Mercury	High-Press. Steam	Low-Press. Turbine	Separator Low Press.	Turbine Discharge	Total Unit	Turbine	Engine and Unit	Hot Well Condensation	Injection	Discharged Circulating Water
5	4	10220	6627	3690	174.4	36.2	12.72	....	28.03	97.08	90.89	3369	150170	153540	136500	149000	88.1	72.1	84.0
6	5	11320	6520	4870	173.4	35.7	17.22	1.52	28.34	96.96	94.09	2759	167190	169950	158200	164850	87.6	74.7	87.8
7	3	11150	6187	4960	173.4	33.9	17.36	2.66	28.55	97.06	90.17	1157	164945	166100	148350	161200	85.5	72.5	86.0
8	3	10970	6178	4840	170.2	49.6	17.36	2.66	28.44	97.15	88.62	654	161612	162270	143200	157700	86.9	74.4	86.6
9	2	11250	6560	4685	170.2	50.1	16.61	1.91	28.18	97.08	92.08	5830	164458	170290	151900	165300	87.8	72.8	86.3
10	1	12440	7060	5400	172.0	49.3	17.60	2.90	27.91	97.54	86.96	3133	185100	188230	161400	183600	89.5	72.0	83.3
11	2	8990	5195	3795	172.0	50.0	16.61	1.91	27.92	97.54	91.32	469	136850	137320	124890	133930	87.3	72.4	83.5
12	1	13240	7580	5610	172.6	48.8	17.06	2.36	27.99	98.32	85.06	6018	192290	198310	163500	194900	90.7	75.4	89.2
13	2	10240	6070	4220	172.0	47.1	16.80	2.10	27.98	98.50	91.05	825	156470	157290	142470	154900	88.2	72.8	83.8
14	2	11480	6140	5340	174.8	51.4	18.84	4.14	28.29	98.41	90.24	337	176210	176550	159010	173740	86.4	73.0	86.6
15	5	11504	6022	5468	170.8	48.1	19.45	4.75	27.51	97.83	95.15	.....	167103	....	159000	....	91.8	78.2	93.5
16	7	11526	6314	5203	173.9	48.4	19.45	4.75	27.42	98.02	93.57	9633	167085	176718	157300	173200	92.9	78.6	91.5
17	5	11528	6084	5488	175.7	49.5	19.90	5.20	27.62	97.70	94.68	5111	179170	184301	169650	180100	86.4	73.6	86.7
18	6	10740	5916	4831	174.1	49.5	18.56	3.86	27.65	98.19	94.83	12554	149148	161702	141450	158750	89.7	72.8	83.6
19	6	14540	7860	6692	174.0	51.7	18.42	3.72	27.78	97.66	95.07	16404	201351	217755	191450	212700	90.9	72.2	88.2
20	4	14365	7373	6962	171.6	52.2	20.94	6.24	27.75	97.88	96.47	15423	196680	212103	189750	207750	90.3	72.6	93.7
21	6	10320	5632	4617	175.9	49.8	17.77	3.07	28.03	97.54	89.52	6486	144399	150885	129150	147100	87.8	72.5	84.4
23	6	13410	7460	5862	173.9	50.2	18.01	3.31	27.72	97.80	96.09	15760	195514	211274	188000	206800	91.1	73.0	87.0
24	6	12927	7033	5820	169.8	50.2	18.59	3.89	27.79	98.03	95.47	14439	173150	187589	165300	183950	89.8	73.3	86.8
25	6	9730	5142	4508	175.3	49.7	18.99	4.29	27.78	97.77	96.46	11189	134635	145824	129840	142600	88.8	72.3	82.8
26	6	11840	6470	5305	172.6	49.2	19.02	4.32	27.48	98.18	96.48	14090	161983	176073	156300	172900	88.2	73.1	84.9
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

TABLE 6 SERIES C

Test No.	Load, Kw.	Results — Water Rates (Dry Steam), Lb. Per Kw-Hr. — Actual: Turbine	Actual: Engine	Actual: Unit	Corrected: Unit Moist	Corrected: Unit Total	Guarantee and Calculated Water Rates, Lb. Per Kw-Hr. — Constant Nozzle Pressure: Turbine	Constant Nozzle Pressure: Engine	Constant Nozzle Pressure: Unit	Circulating Water: Ratio Circ. Water / Dry Steam	Circulating Water: Total Gal. per Min.	Water Rate, Unit Equivalent, Lb. per I.h.p. Hr. Constant nozzle press.	Remarks	Formulae and Notes
5	10220	36.98	22.48	14.57	14.0	13.53	28.42	26.03	14.42	89.0	26740	8.85	Varying nozzle pressure	$27 = \frac{17}{4 + [1 + (1-12)]5}$
6	11320	32.34	25.30	14.45	14.1	13.94	27.30	26.04	14.07	80.5	26920	8.68	Auxiliary steam included constant nozzle pressure	
7	11150	30.42	26.05	14.49	13.85	13.90	27.22	26.07	14.10	78.3	25800	9.10	Constant nozzle pressure	$28 = 27-(285-10)$
8	10970	29.58	25.51	14.37	13.64	13.70	27.31	26.07	14.15	86.5	27960	8.76	Constant nozzle pressure	
9	11250	32.42	25.20	14.69	14.23	13.55	27.42	26.04	14.09	79.0	25980	9.03	Constant nozzle pressure	
10	12440	29.89	26.01	14.76	13.95	13.36	27.00	26.08	13.88	93.5	30560	8.27	Varying nozzle pressure	
11	8990	32.91	25.79	14.89	14.36	13.78	28.29	26.99	15.10	94.5	25820	8.76	Constant nozzle pressure	
12	13240	29.15	25.71	14.72	13.90	13.39	26.90	26.46	13.90	76.5	30320	8.25	Constant nozzle pressure	
13	10240	33.76	25.52	15.13	14.51	13.99	27.83	26.10	14.41	96.0	30200	9.01	Constant nozzle pressure	
14	11480	29.78	28.30	15.15	14.47	14.26	27.02	26.10	14.03	78.6	25000	9.14	Varying nozzle pressure	
15	11504	29.06	....	....	....	....	26.97	26.24	14.01	69.0	23060	....	Auxiliary included constant nozzle pressure	
16	11526	30.22	27.42	15.02	14.64	13.56	27.10	26.12	14.01	82.0	27400	8.93	Constant nozzle pressure	
17	11528	30.90	29.70	15.68	15.20	14.32	26.96	26.20	14.01	81.0	29020	9.53	Auxiliary included varying nozzle pressure	
18	10740	29.26	26.84	14.78	14.41	13.56	27.31	26.30	14.22	98.0	29230	9.06	Constant nozzle pressure	
19	14540	28.60	27.05	14.62	14.30	13.58	26.63	26.69	13.80	66.0	26560	9.08	Constant nozzle pressure	
20	14365	27.23	28.15	14.45	14.25	13.50	26.60	26.31	13.80	51.0	20050	9.05	Varying nozzle pressure	
21	10320	27.97	26.11	14.25	13.70	13.23	27.49	26.50	14.39	85.0	24520	8.52	Constant nozzle pressure	
23	13410	32.05	27.70	15.41	15.25	14.47	26.81	26.37	13.80	75.5	29520	9.81	Constant nozzle pressure	
24	12927	28.40	26.14	14.22	14.0	14.29	26.82	26.16	13.81	78.5	27180	8.93	Constant nozzle pressure	
25	9730	28.81	27.73	14.65	14.53	13.81	27.57	27.07	14.67	101.0	27200	9.33	Constant nozzle pressure	
26	11840	29.45	26.71	14.60	14.44	13.42	27.04	26.09	13.96	91.0	24500	9.06	Constant nozzle pressure	

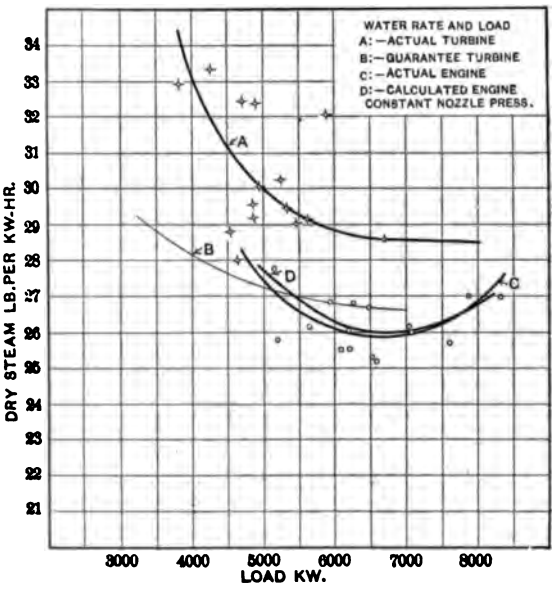


FIG. 15a SERIES C

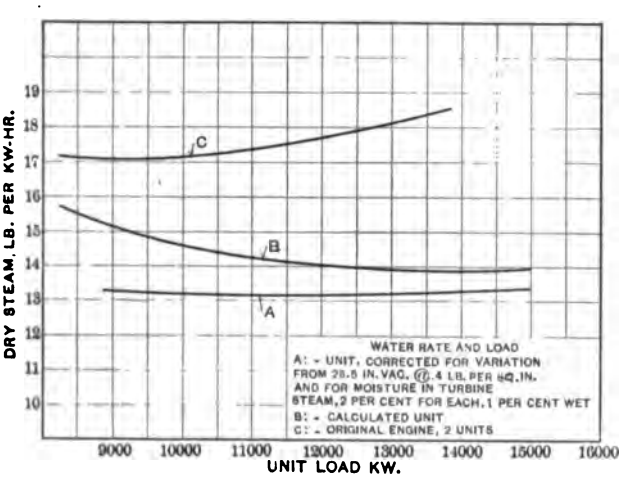


FIG. 15b SERIES C

TABLE 6 SERIES C

Test No.	Load, Kw.	Results: Water Rates (Dry Steam), Lb. Per Kw-Hr. — Actual: Turbine	Actual: Engine	Actual: Unit	Corrected: Unit Moist	Corrected: Unit Total	Guarantee and Calculated Water Rates, Lb. Per Kw-Hr. — Constant Nozzle Pressure: Turbine	Constant Nozzle Pressure: Engine	Constant Nozzle Pressure: Unit	Circulating Water: Ratio Circ. Water / Dry Steam	Circulating Water: Total Gal. per Min.	Water Rate, Unit Equivalent, Lb. per I.h.p- Hr. Constant nozzle press.	Remarks	Formulae and Notes
5	10220	36.98	22.48	14.57	14.0	13.53	28.42	26.03	14.42	89.0	26740	8.85	Varying nozzle pressure	$27=\frac{17}{4+[1+(1-12)]5}$
6	11320	32.34	25.30	14.45	14.1	13.94	27.30	26.04	14.07	80.5	26920	8.68	Auxiliary steam included constant nozzle pressure	
7	11150	30.42	26.05	14.49	13.85	13.90	27.22	26.07	14.10	78.3	25800	9.10	Constant nozzle pressure	28 = 27-(285-10)
8	10970	29.58	25.51	14.37	13.64	13.70	27.31	26.07	14.15	86.5	27960	8.76	Constant nozzle pressure	
9	11250	32.42	25.20	14.69	14.23	13.55	27.42	26.04	14.09	79.0	25980	9.03	Constant nozzle pressure	
10	12440	29.89	26.01	14.76	13.95	13.36	27.00	26.08	13.88	93.5	30560	8.27	Varying nozzle pressure	
11	8990	32.91	25.79	14.89	14.36	13.78	28.29	26.99	15.10	94.5	25820	8.76	Constant nozzle pressure	
12	13240	29.15	25.71	14.72	13.90	13.39	26.90	26.46	13.90	76.5	30320	8.25	Constant nozzle pressure	
13	10240	33.76	25.52	15.13	14.51	13.99	27.83	26.10	14.41	96.0	30200	9.01	Constant nozzle pressure	
14	11480	29.78	28.30	15.15	14.47	14.26	27.02	26.10	14.03	78.6	25000	9.14	Varying nozzle pressure	
15	11504	29.06	....	....	....	....	26.97	26.24	14.01	69.0	23060	....	Auxiliary included constant nozzle pressure	
16	11526	30.22	27.42	15.02	14.64	13.56	27.10	26.12	14.01	82.0	27400	8.93	Constant nozzle pressure	
17	11528	30.90	29.70	15.68	15.20	14.32	26.96	26.20	14.01	81.0	29020	9.53	Auxiliary included varying nozzle pressure	
18	10740	29.26	26.84	14.78	14.41	13.56	27.31	26.30	14.22	98.0	29230	9.06	Constant nozzle pressure	
19	14540	28.60	27.05	14.62	14.30	13.58	26.63	26.69	13.80	66.0	26560	9.08	Constant nozzle pressure	
20	14365	27.23	28.15	14.45	14.25	13.50	26.60	26.31	13.80	51.0	20050	9.05	Varying nozzle pressure	
21	10320	27.97	26.11	14.25	13.70	13.23	27.49	26.50	14.39	85.0	24520	8.52	Constant nozzle pressure	
23	13410	32.05	27.70	15.41	15.25	14.47	26.81	26.37	13.80	75.5	29520	9.81	Constant nozzle pressure	
24	12927	28.40	26.14	14.22	14.0	14.29	26.82	26.16	13.81	78.5	27180	8.93	Constant nozzle pressure	
25	9730	28.81	27.73	14.65	14.53	13.81	27.57	27.07	14.67	101.0	27200	9.33	Constant nozzle pressure	
26	11840	29.45	26.71	14.60	14.44	13.42	27.04	26.09	13.96	91.0	24500	9.06	Constant nozzle pressure	

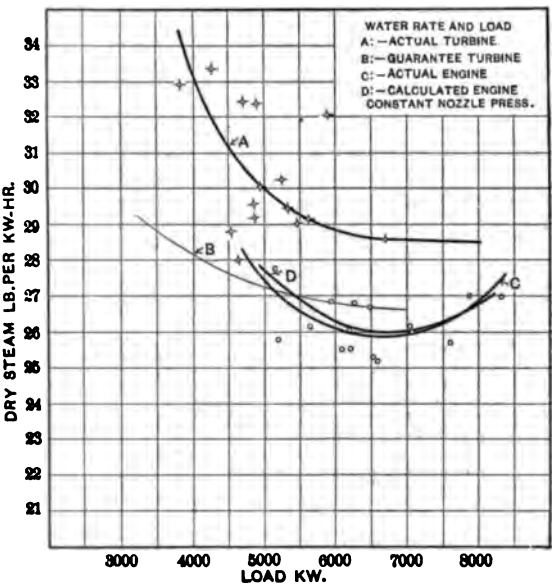


FIG. 15a SERIES C

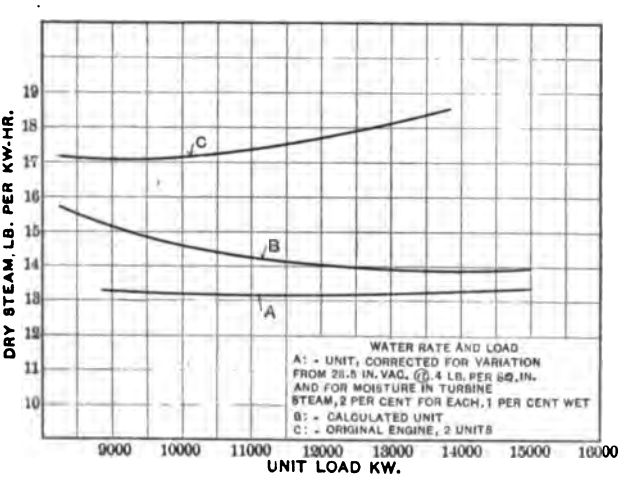


FIG. 15b SERIES C

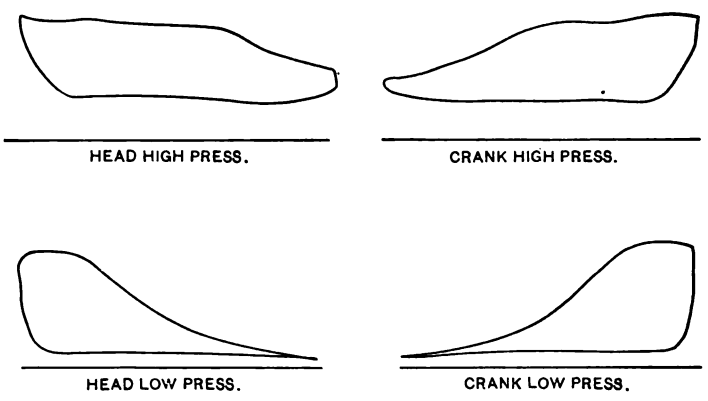


FIG. 16 SERIES C

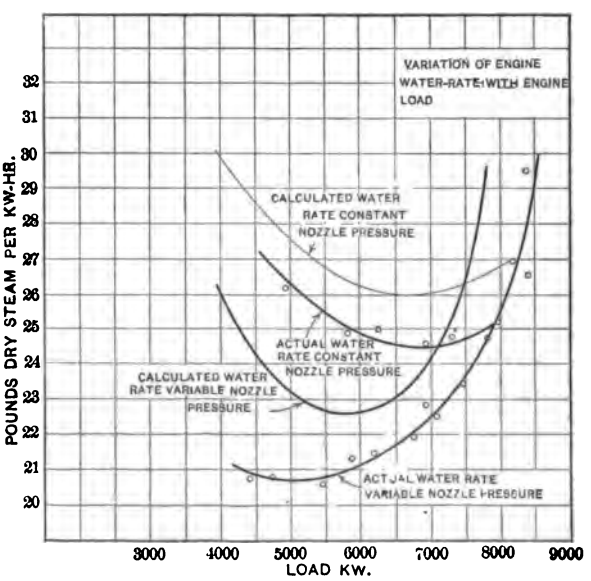


FIG. 17 SERIES E AND F

Test No.	Duration, Hour	Unit	Engine	Turbine	High-Press. Stea per Sq. In. Ab	Receivers, Lb. p In. Abs.	Turbine Steam, l Sq. In. Abs.	Vacuum, Lb. pe In. Abs.	Vacuum 29.92 In rometer In. Me	High-Press. Ste Per Cent	Turbine Steam Cent	Total Condens	Turbine Water	Total Water Ur	Turbine	Engine and Un	Condenser Hot Deg. Fahr.	Circulating Wat jection, Deg. F	Circulating Wa Discharge, Deg.
27	6	9567	4875	4683	185.1	64.7	18.14	0.70	28.50	99.0	93.4	8636	133840	142476	125000	141100	78.6	38.80	58.60
28	6	10537	5819	4714	189.8	64.9	16.93	0.87	28.15	99.6	95.2	8570	146730	155300	139700	154700	80.4	39.53	67.04
29	2	11400	6410	5000	184.7	65.2	17.62	1.06	27.87	98.9	97.3	9601	162475	172076	158100	170300	81.3	37.40	67.77
30	4	11365	6590	4810	185.6	64.9	17.62	1.15	27.58	99.0	97.8	10088	161351	171439	157800	169700	84.5	29.20	73.90
31	6	12300	6930	5373	192.0	65.5	17.59	0.90	28.12	99.3	97.8	11006	166826	177832	163200	176600	78.64	36.54	66.00
32	6	13160	7490	5717	193.4	66.3	17.66	0.95	27.98	99.5	97.2	12142	179776	191918	174700	191000	75.34	35.70	69.72
33	4	16085	8505	7670	192.3	65.2	20.00	1.12	27.64	99.8	94.7	7312	247090	254402	234000	254000	86.44	35.05	73.41
34	6	14223	8183	6060	192.3	65.8	17.56	1.11	27.66	99.4	95.7	9361	206261	215622	197500	214300	89.06	34.88	74.30
35	4	13295	7183	5524	194.7	65.8	17.13	1.20	27.49	99.5	95.4	11145	187214	198359	178600	197500	90.85	35.22	76.39
36	5	12217	769	5033	192.7	64.3	16.28	1.05	27.78	99.8	93.8	13017	165908	178925	155500	178700	89.42	34.66	70.76
37	6	10043	7113	4184	190.4	63.9	16.40	1.02	27.84	99.4	93.7	9823	140932	150755	132000	149800	91 80	36.67	70.72

Test No.	Actual Water-Rates: Engine	Actual Water-Rates: Turbine	Actual Water-Rates: Unit	Corrected Unit: Moisture	Corrected Unit: Moisture and Vacuum						I.h.p. Engine: High-Press.	I.h.p. Engine: Low-Press.	Total	Factor I.h.p./Kw.
27	28.94	2765	14.75	14.30	14.30	....	....	....	....	....	3861	3502	7363	1.511
28	26.69	30.15	14.68	14.37	14.02	....	....	....	....	....	4138	4359	8497	1.461
29	26.57	1.62	14.94	14.74	14.11	....	....	....	....	....	4445	4712	9157	1.429
30	25.97	20.81	14.93	14.74	18.82	....	....	....	....	....	4477	4727	9204	1.397
31	25.44	83.38	14.86	14.22	13.74	....	....	....	....	....	4753	5045	9798	1.414
32	25.77													
		30.57	14.51	14.29	13.77	....	....	....	....	....	5092	5583	10675	1.425
33		30.50	15.79	15.32	13.46	....	....	....	....	....	5902	6229	12131	1.426
96		32.60	15.07	14.78	13.94	....	....	....	....	....	5585	6018	11603	1.417
96		32.34	14.85	14.56	13.55	....	....	....	....	....	5246	5682	10928	1.404
25		30.91	14.62	14.29	13.57	....	....	....	....	....	4873	5421	10294	1.435
50		31.54	14.93	14.60	13.94	....	....	....	....	....	4248	4312	8560	1.478

TABLE 8 SERIES E AND F

Test No.	Date	Duration, Hours	Loads, Kw.			Pressures													Circulating Water Pump	
			Total Unit	Engine	Turbine	Main Steam Abs. Lb. per Sq. In.	Main Steam Gage Lb. per Sq. In.	Receivers Abs. Lb. per Sq. In.	Receivers Gage Lb. per Sq. In.	Low-Press. Separator Abs. Lb. per Sq. In.	Low-Press. Separator Gage Lb. per Sq. In.	Low-Press. Separator Unit Tube, In. Mercury	Vacuum Mercury Column In. Mercury	Vacuum Abs. Manom. In. Mercury Abs.	Vacuum Abs. Lb. Abs.	Barometer, In. Mercury	Standard Vacuum 29.92 In. Barometer In. Mercury	Suction, In. Mercury	Discharge Gage, Lb. per Sq. In.
	1910																			
38	Jan. 11	5	16172	8384	7784	197.0	182.3	64.2	49.5	20.60	5.90	10.94	29.30	1.50	0.74	30.63	28.42	12.7	12.0
39	11	5	13485	7798	5895	203.8	189.1	64.5	49.8	16.50	1.80	2.61	29.10	1.58	0.78	30.59	28.34	12.2	12.9
40	12	5	13038	7314	5711	196.1	181.4	63.8	49.1	16.20	1.50	1.82	29.46	1.22	0.60	30.61	28.72	11.0	12.8
41	12	5	12284	6938	5348	200.2	185.5	64.5	49.8	16.10	1.40	2.18	29.32	1.31	0.64	30.57	28.69	12.6	12.1
42	13	5	11252	6248	4938	197.0	182.3	64.0	49.3	16.24	1.54	2.20	29.41	1.32	0.65	30.65	28.60	9.9	14.3
43	13	5	10476	5824	4602	198.0	183.3	63.8	49.1	16.20	1.50	2.00	29.23	1.46	0.72	30.58	28.46	12.6	12.8
44	14	5	9408	4940	4426	198.8	184.1	63.8	49.1	16.10	1.40	2.28	29.47	0.93	0.46	30.31	28.99	9.5	11.6
45	14	1½	9712	5916	3709	198.2	183.5	64.3	49.6	10.50	....	−7.48	28.96	1.22	0.60	30.21	28.70	11.6	11.6
46	15	½	12700	7180	5640	198.5	183.8	62.6	47.9	12.96	....	−2.78	29.45	1.03	0.51	30.32	28.89	13.75	9.5
47	15	½	11940	7060	4780	195.3	180.6	62.6	47.9	12.35	....	−1.80	29.72	1.03	0.51	30.32	28.89	12.9	9.9
48	15	3	9306	5865	3323	196.3	181.5	63.8	49.1	9.65	....	−10.49	29.13	1.20	0.59	30.33	28.72	12.0	10.6
								46.3	31.6										
49	15	1	10940	6640	4300	194.9	180.2	49.3	35.6	11.65	....	−6.62	29.19	1.13	0.56	30.32	28.79	12.1	10.9
50	15	4	15498	8169	7260	192.0	177.3	59.0	44.3	17.80	3.10	3.54	29.23	1.13	0.56	30.32	28.79	14.6	10.4
51	17	3	11240	6753	4376	194.0	179.3	55.0	40.3	11.50	....	−6.71	29.25	1.19	0.58	30.38	28.73	11.5	9.9
52	17	3	7200	4743	2400	196.5	181.8	41.5	26.8	7.97	....	−14.92	29.07	1.29	0.63	30.29	28.63	10.6	10.7
53	17	3	11927	7070	4834	199.0	184.3	52.9	38.2	12.75	....	4.58	29.10	1.25	0.61	30.26	28.67	13.2	10.1
54	26	3	14173	7820	6283	193.4	178.6	55.7	40.9	15.18	0.48	1.04	29.31	0.93	0.46	30.03	28.99	10.1	9.5
55	26	3	8347	5403	2910	197.4	182.7	43.0	28.3	8.21	....	−13.48	28.90	1.15	0.57	29.97	28.77	12.4	9.0
56	26	3	13033	7457	5550	197.2	182.5	54.3	39.6	14.09	....	− 1.75	29.01	1.01	0.50	29.90	28.91	13.2	9.4
57	27	3	14580	7960	6583	199.7	179.2	59.6	45.1	15.57	0.87	+3.04	28.85	0.85	0.42	29.49	29.07	10.3	8.8
58	27	3	6673	4420	2213	197.7	183.2	40.1	25.6	7.08	....	−15.14	28.48	0.98	0.48	29.48	28.94	12.6	8.6
59	27	3	10007	6194	3804	199.1	184.6	47.3	32.0	10.35	....	− 8.59	28.55	0.94	0.46	29.50	28.98	14.3	8.7
60	28	3	11820	6923	4860	195.1	180.5	51.6	36.9	12.10	....	− 4.98	28.96	0.87	0.43	29.79	29.05	10.7	10.4

Test No.	Load, Kw.	Average Main Steam Temperature, Deg. Fahr.	Calorimeter Discharge Temperature, Deg. Fahr.	Calorimeter Discharge Press. (Gage), In. Mercury	Quality, Per Cent	Moisture, Lb.	Flow, Lb.	Quality, Per Cent	Steam Temperature, Deg. Fahr	Discharge Temperature, Deg. Fahr.	Discharge Press. Vacuum, In. Mercury	Quality, Per Cent	Discharge Temperature, Deg. Fahr.	Discharge Press. Vacuum, In. Mercury	Quality, Per Cent
38	16172	380.6	312.1	18.27	99.5	11.55	153.43	92.9	.....	.....	.....	99.2	.....	.....	.....
39	13485	383.4	282.0	25.68	97.9	10.49	117.59	91.8	.....	217.6	20.31	98.8	.....	.....	.....
40	13036	380.2	302.9	21.81	99.2	10.10	119.41	92.2	.....	216.7	20.74	98.8	.....	.....	.....
41	12284	381.9	297.5	19.80	98.9	9.88	119.93	92.4	.....	216.3	20.55	98.7	.....	.....	.....
42	11252	380.6	294.8	20.77	98.7	9.73	120.16	92.6	1.42	18.77	93.0	216.7	181.5	20.60	98.7	164.0	26.12	98.1
43	10476	381.0	291.8	20.42	98.5	8.86	111.94	92.6	3.18	46.47	93.6	216.7	182.9	21.50	98.8	168.9	26.23	98.4
44	9408	381.3	297.9	21.78	98.7	8.05	99.50	92.5	1.08	18.90	94.6	216.4	179.3	21.55	98.6	177.0	25.71	98.5
45	9712	381.1	294.8	21.92	98.7	1.10	14.10	92.8	0.79	11.96	93.8	195.4	172.5	23.70	99.2	159.5	27.37	98.6
46	12700	381.2	296.7	21.40	98.8	0.42	10.60	96.1	0.16	4.00	96.2	210.2	170.3	21.30	98.4	163.9	26.40	98.3
47	11940	379.9	304.0	20.63	99.1	0.29	9.10	96.9	0.16	3.60	95.8	208.3	176.0	22.48	98.9	165.7	26.72	98.6
48	9306	380.3	290.5	21.18	98.6	2.43	42.25	94.6	1.22	16.88	93.3	191.8	171.2	24.29	99.3	156.9	27.42	98.6
49	10940	379.7	299.0	21.05	98.9	0.74	16.77	95.7	0.41	6.90	94.4	200.3	178.3	22.62	99.3	167.3	26.76	98.7
50	15498	378.5	305.6	19.77	99.4	2.84	70.70	96.2	1.27	41.56	97.0	221.4	180.4	19.89	98.8	182.9	25.40	98.6
51	11240	379.4	292.6	21.93	98.6	2.04	51.67	96.2	1.15	19.96	94.5	199.8	174.8	22.68	99.0	165.0	27.04	99.1
52	7200	380.4	288.8	20.71	98.4	2.04	36.77	94.7	0.93	14.05	93.7	182.4	163.0	25.21	98.3	148.0	27.75	98.6
53	11927	381.4	294.4	20.64	98.6	1.79	56.20	95.3	1.11	21.66	95.1	204.7	177.0	21.96	99.0	168.8	26.73	98.7
54	14173	379.1	296.9	22.41	98.9	2.13	56.70	96.3	.....	.....	.....	213.3	191.4	19.92	99.4	.....	.....	.....
55	8347	380.8	292.9	20.87	98.6	1.57	38.91	96.1	.....	.....	.....	184.2	165.2	24.20	99.3	.....	.....	.....
56	13033	380.7	298.2	20.25	98.7	1.63	61.64	97.4	.....	.....	.....	209.7	184.9	20.81	99.1	.....	.....	.....
57	14580	379.2	298.8	21.75	99.0	2.06	70.87	97.2	.....	.....	.....	215.3	188.9	18.77	99.0	.....	.....	.....
58	6673	380.9	298.4	21.80	99.0	1.79	33.80	94.9	.....	.....	.....	178.4	161.1	24.41	99.4	.....	.....	.....
59	10007	381.5	287.0	21.53	98.2	2.62	47.12	94.7	.....	.....	.....	194.8	171.1	22.70	99.2	.....	.....	.....
60	11820	379.8	299.9	21.34	99.0	1.56	54.77	97.2	.....	.....	.....	202.4	176.0	21.67	99.0	.....	.....	.....
61	11480	380.5	302.8	21.00	99.1	1.55	55.79	97.3	.....	.....	.....	203.3	178.4	21.57	99.0	.....	.....	.....
62	15860	379.7	299.7	20.63	99.0	2.19	80.02	97.3	.....	.....	.....	221.9	197.6	17.87	99.3	.....	.....	.....

TABLE 10 SERIES E AND F

Test No.	Watt-Hours	Thomas Calorimeter: Steam Temperature, Deg. Fahr.	Thomas Calorimeter: Calorimeter Discharge Temperature, Deg. Fahr.	Thomas Calorimeter: Calorimeter Discharge Water, Lb.	Thomas Calorimeter: Quality, Per Cent	Exhaust From Engine: Separating Calorimeter: No. 1 Combined Quality, Per Cent	Exhaust From Engine: Separating Calorimeter: No. 2 Combined Quality, Per Cent	Exhaust From Engine: Separating Calorimeter: Average Quality, Per Cent	Exhaust From Engine: Separating Calorimeter: Moisture, Lb.	Exhaust From Engine: Separating Calorimeter: Flow, Lb.	Exhaust From Engine: Throttling Calorimeter: Quality, Per Cent	Exhaust From Engine: Throttling Calorimeter: Steam Temperature, Deg. Fahr.	Exhaust From Engine: Throttling Calorimeter: Calorimeter Discharge Temperature, Deg. Fahr.	Exhaust From Engine: Throttling Calorimeter: Calorimeter Discharge Pressure, In. Mercury	Exhaust From Engine: Throttling Calorimeter: Quality, Per Cent	Exhaust From Engine: Throttling Calorimeter: Combined Quality, Per Cent	Exhaust From Engine: Quality by Separator Water and Turbine Steam Quality, Per Cent
38	6600	229.2	414.6	93.90	84.1	92.2	.....	90.2	.....	.....	.....	.....	.....	.....	.....	.....	.....
39	5623	217.6	430.6	84.10	86.3	90.7	.....	89.4	.....	.....	.....	.....	.....	.....	.....	.....	.....
40	4758	216.7	429.9	93.60	92.4	91.1	.....	91.5	.....	.....	.....	.....	.....	.....	.....	.....	.....
41	3242	216.3	412.7	70.20	93.2	91.2	.....	91.9	.....	.....	.....	.....	.....	.....	.....	.....	.....
42	4268	216.7	426.8	110.20	94.4	91.4	91.2	93.0	.....	.....	.....	.....	.....	.....	.....	.....	.....
43	5000	216.7	408.3	116.50	94.3	91.5	92.1	92.6	.....	.....	.....	.....	.....	.....	.....	.....	.....
44	4575	216.4	424.6	88.80	91.9	91.2	93.2	92.1	.....	.....	.....	.....	.....	.....	.....	.....	.....
45	1519	195.4	445.2	30.90	94.9	92.0	92.5	93.1	.....	.....	.....	.....	.....	.....	.....	.....	.....
46	500	210.2	356.9	20.40	98.5	94.6	94.6	95.9	.....	.....	.....	.....	.....	.....	.....	.....	.....
47	350	203.3	454.2	27.40	95.6	95.8	94.5	95.3	.....	.....	.....	.....	.....	.....	.....	.....	.....
48	2100	191.8	420.0	37.92	91.7	93.9	92.0	92.5	.....	.....	.....	.....	.....	.....	.....	.....	.....
49	.....	.....	.....	.....	.....	95.0	93.2	94.1	.....	.....	.....	.....	.....	.....	.....	.....	.....
50	2377	221.4	346.5	81.70	95.8	95.0	94.4	95.1	.....	.....	.....	.....	.....	.....	.....	.....	.....
51	2100	199.8	430.7	47.70	95.4	95.2	93.6	94.7	.....	.....	.....	.....	.....	.....	.....	.....	.....
52	2300	182.4	395.5	58.40	96.5	94.0	92.4	94.3	.....	.....	.....	.....	.....	.....	.....	.....	.....
53	2500	204.7	433.2	59.00	96.2	94.3	93.8	94.8	.....	.....	.....	.....	.....	.....	.....	.....	.....
54	650	213.3	276.7	44.05	98.0	96.7	.....	96.9	2.53	26.90	91.4	213.8	180.5	23.29	98.7	90.2	89.6
55	600	184.2	293.6	28.10	97.4	95.4	.....	96.4	2.05	15.17	88.1	185.6	148.7	26.71	98.5	86.8	90.2
56	600	209.7	268.5	44.40	98.1	96.5	.....	97.8	2.53	21.70	89.5	209.5	167.7	25.41	98.6	88.2	90.3
57	600	215.3	280.8	56.10	98.4	96.2	.....	97.3	1.92	21.40	91.8	216.2	172.1	25.16	98.4	90.3	89.3
58	450	178.4	267.7	24.90	97.0	94.4	.....	95.7	1.88	17.12	90.7	177.9	148.3	25.80	98.8	89.0	89.7
59	600	194.8	266.5	33.80	97.2	94.0	.....	95.6	2.28	15.72	87.3	195.3	154.0	26.02	98.5	86.0	89.8

Test No.	West Main Steam. Deg. Fahr.	East Main Steam. Deg. Fahr.	Average Main Steam Deg. Fahr.	West Receiver. Deg. Fahr.	East Receiver. Deg. Fahr.	Average Receiver. Deg. Fahr.	East Engine Exhaust. Deg. Fahr.	East Separator Inlet. Deg. Fahr.	Separator Outlet. Deg. Fahr.	Turbine Bowl. Deg. Fahr.	Condenser. Deg. Fahr.	Hot Well Water. Deg. Fahr.	Circulating Water Injection. Deg. Fahr.	Circulating Water Discharge. Deg. Fahr.
38	381.0	380.2	380.6	297.0	297.4	297.2	230.5	220.1	229.2	228.5	90.90	71.20	37.66	57.28
39	384.1	382.8	383.4	297.3	297.4	297.4	218.7	.....	217.6	217.0	94.60	76.23	39.85	62.51
40	380.3	380.1	380.2	296.1	297.5	296.8	218.0	217.6	216.7	216.1	84.45	70.97	32.03	51.84
41	382.4	381.4	381.9	297.0	297.7	297.3	217.9	217.2	216.3	216.3	87.17	73.41	33.95	56.76
42	380.2	380.9	380.6	296.9	297.0	297.0	218.6	218.6	216.9	216.9	87.18	75.25	31.82	56.67
43	380.6	381.3	381.0	296.8	296.6	296.7	217.9	.....	216.7	216.3	89.32	80.17	32.75	57.14
44	380.3	382.2	381.3	296.9	296.5	296.7	217.6	.....	216.4	216.1	73.87	59.42	31.63	41.98
45	380.3	381.8	381.1	296.8	297.7	297.3	208.2	.....	195.4	196.7	86.72	66.20	32.22	43.97
46	379.7	382.7	381.2	295.0	296.0	295.5	209.0	.....	210.2	208.0	77.20	63.70	40.20	53.10
47	379.0	380.8	379.9	295.3	296.0	295.6	205.0	.....	203.3	204.0	80.00	63.00	36.00	46.85
48	379.6	381.0	380.3	297.1	296.4	296.7	193.7	.....	.....	192.5	.....	.....	.....	.....
49	377.8	381.6	379.7	279.6	275.8	276.1	190.5	.....	191.8	189.4	84.86	60.58	32.90	42.06
50	376.7	380.2	378.5	291.5	291.5	291.5	222.6	.....	221.4	221.0	83.50	62.60	31.38	53.86
51	379.0	379.8	379.4	287.2	286.8	287.0	203.4	.....	199.8	199.8	82.23	65.69	31.51	50.08
52	379.7	381.0	380.4	268.9	270.2	269.6	183.8	.....	182.4	180.8	83.16	65.18	37.50	43.10
53	380.5	382.3	381.4	285.5	283.2	284.4	206.7	.....	204.7	204.6	85.70	58.15	31.47	39.81
54	376.3	381.8	379.1	287.1	288.7	287.9	215.6	.....	213.3	213.3	83.65	65.65	31.46	45.37
55	378.0	383.5	381.8	271.8	271.7	271.7	187.0	.....	184.2	183.8	81.20	57.26	33.54	47.77
56	378.4	383.0	380.7	285.8	286.5	286.2	209.3	.....	209.7	207.6	81.00	58.64	33.08	41.30
57	377.0	381.4	379.2	293.0	291.6	292.3	217.5	.....	214.9	215.5	74.70	60.72	33.40	50.10
58	379.4	382.5	380.9	267.5	267.9	267.7	177.4	.....	177.4	176.3	67.41	53.21	33.28	47.60
59	380.0	383.0	381.5	277.5	277.4	277.5	195.7	.....	194.8	194.1	78.20	53.85	33.18	39.46
60	377.9	381.7	379.8	283.2	283.0	283.1	204.4	.....	202.4	202.4	78.30	59.12	33.40	43.66
61	378.5	382.4	380.5	283.0	282.5	282.8	205.0	.....	203.3	203.2	74.04	59.60	33.25	46.00
62	377.5	381.8	379.7	296.3	296.3	296.3	223.9	.....	221.9	221.8	77.18	61.74	33.06	47.23
											82.42	62.79	33.64	56.00

TABLE 12 SERIES E AND F

Test No.	Load. Kw.	Water, Lb. per Hour: Turbine Water	Turbine Water Venturi	Separator and Traps	Separator Water	Traps Venturi	Total Enclosed Water	Dry Steam Engine	Dry Steam Turbine	Water, Lb. per Kw-Hr.: Actual Unit	Actual Engine	Actual Turbine	Unit Rate Corrected for Moisture only	Unit Rate Corrected for Moisture and Vacuum	I.H.P.: Average High Press.	Average Low Press.	Total	Factor I.h.p. per Kw.
38	16172	237480	.....	7425	7175	250	244905	243700	214200	15.07	29.54	27.51	14.40	14.10	5640	6117	11757	1.404
39	13485	187193	.....	9883	5881	4002	197076	193000	167400	14.32	24.76	28.38	13.48	13.10	5104	5847	10951	1.404
40	13038	170661	.....	12271	6281	5980	182932	181500	156200	13.92	24.78	27.35	13.44	13.42	4931	5650	10581	1.447
41	12284	160229	.....	12064	3628	8436	172293	170400	147200	13.88	24.57	27.51	13.39	13.28	4800	5306	10106	1.457
42	11252	147142	.....	10927	2607	8320	158069	156100	136900	13.87	24.99	27.72	13.54	13.42	4250	4330	8580	1.374
43	10476	138766	.....	9939	1801	7138	147153	145000	128500	13.85	24.90	27.91	13.47	13.21	4227	4280	8507	1.460
44	9408	122689	.....	8387	227	8160	131076	129400	113000	13.75	26.19	25.53	13.32	13.59	3771	3490	7261	1.470
45	9712	121870		13160	4910	8250	135030	133300	113500	13.72	22.53	30.59	13.49	13.45	3819	4367	8186	1.385
46	12700	160960	.....	18874	11242	7632	179834	177700	154400	13.99	24.75	27.38	13.62	13.77	4994	6313	11307	1.575
47	11940	142740	.....	17385	8935	8450	160125	158700	136000	13.30	22.49	28.45	13.15	13.31	4675	5736	10411	1.475
48	9306	114372	.....	12555	4744	7811	126927	125100	105800	13.44	21.34	31.84	13.25	13.25	4129	4321	8450	1.441
49	10940	134785	.....	16565	8357	8308	151350	149700	126900	13.69	22.40	29.50	13.39	13.46	5039	4545	9584	1.444
50	15498	202656	.....	19161	16661	2500	221817	220400	192900	14.22	26.99	26.55	13.96	14.03	5784	5825	11609	1.421
51	11240	133462	.....	16689	8399	8290	150151	148100	126500	13.19	21.95	28.89	13.04	13.04	4585	5244	9829	1.456
52	7200	89158	.....	10881	7170	3691	100019	98400	84080	13.67	20.75	35.04	13.52	13.43	3662	3478	7140	1.505
53	11927	143897	.....	17901	8164	9737	161798	159500	136500	13.38	22.57	28.22	13.13	13.08	4995	4897	9892	1.400
54	14173	176565	.....	19180	12930	6250	195745	193600	171050	13.66	24.75	27.22	13.54	13.81	5430	5370	10800	1.400
55	8347	99210	.....	13733	6183	7550	112943	111400	95620	13.34	20.60	32.85	13.23	13.28	3907	3792	7699	1 425
56	13033	158112	.....	18849	11159	7690	176961	174700	153850	13.40	23.43	27.72	13.28	13.47	5115	5120	10235	1.373
57	14580	182508	.....	20011	14741	5270	202599	200700	177600	13.75	25.19	26.95	13.65	14.00	5376	5673	11049	1.388
58	6673	81533	.....	11225	4906	6325	92958	91800	78000	13.76	20.78	35.27	13.65	13.87	3282	3170	6452	1.460
59	10007	120863	.....	14578	6478	8100	135441	133050	115600	13.30	21.48	30.38	13.13	13.39	4452	4294	8746	1.413
60	11820	141930	.....	17833	9873	7960	159763	158200	138100	13.38	22.84	28.41	13.28	13.61	5108	4796	9904	1.431
61	11480	143958	.....	17101	8791	8310	161059	159600	141500	13.92	24.45	24.22	13.75	13.95	4728	4594	9322	1.414
62	15860	206603	.....	19762	15705	4057	226365	224200	201300	14.14	26.58	26.56	13.99	13.99	5750	6538	12288	1.456

TABLE 13 SERIES E AND F

B.T.U. DISTRIBUTION: UNIT IS 1,000,000 B.T.U.

Test No.	Total load, Kw.	Supplied to Unit		Supplied to Turbine only		Engine Output Kw.		Turbine Output Kw.		Total Output Kw.		To Condenser		To Hot Well		Lost by Radiation, etc.	
		B.t.u.	Per Cent	B.t.u.	Per Cent	B.t.u.	Per Cent	B.t.u.	Per Cent	B.t.u.	Per Cent	B.t.u.	Per Cent	B.t.u.	Per Cent	B.t.u.	Per Cent
38	16172	292.0	100	252.5	86.5	28.61	9.8	26.58	9.1	55.19	18.9	216.6	74.2	9.31	3.2	10.89	3.7
39	13485	232.6	....	196.6	84.6	26.36	11.3	19.88	8.6	46.27	19.9	168.4	72.4	8.28	3.6	9.64	4.1
40	13038	218.0	....	182.5	83.7	24.97	11.5	19.49	8.9	44.46	20.4	156.4	71.7	6.65	3.1	10.53	4.8
41	12284	204.7	....	171.8	83.9	23.67	11.6	18.25	8.9	41.92	20.5	146.9	71.7	6.64	3.2	9.23	4.5
42	11252	187.7	....	159.5	85.0	21.35	11.4	16.95	9.0	38.37	20.5	136.2	72.5	6.36	3.4	6.85	3.7
43	10476	174.5	....	149.8	85.9	19.93	11.4	15.76	9.0	35.68	20.5	127.3	73.0	6.69	3.8	4.77	2.7
44	9408	155.8	....	131.9	84.6	16.87	10.8	15.12	9.7	32.09	20.6	113.4	72.7	3.36	2.2	7.03	4.5
45	9712	.....	....	.....	....	.....	.....	.....	....	.....	....	.....	....	.....	....	.....	...
46	12700	.....	....	.....	....	.....	.....	.....	....	.....	....	.....	....	.....	....	.....	...
47	11940	.....	....	.....	....	.....	.....	.....	....	.....	....	.....	....	.....	....	.....	...
48	9306	150.5	....	122.3	81.3	20.14	13.4	1146	7.6	31.61	21.0	107.6	71.5	3.27	2.2	8.06	5.4
49	10940	.....	....	.....	....	.....	....	.....	....	.....	....	.....	....	....	....	.....	...
50	15498	264.2	....	224.2	84.8	27.95	10.6	24.85	9.4	52.56	19.9	192.5	72.8	6.83	3.6	12.05	4.6
51	11240	178.0	....	146.0	81.8	23.16	13.0	15.05	8.4	37.85	21.3	126.5	70.9	4.43	2.5	8.84	5.0
52	7200	118.4	....	96.41	81.4	16.25	13.7	8.26	7.0	24.37	20.6	85.8	72.5	2.33	2.0	5.74	4.8
53	11927	191.8	....	157.8	82.3	24.16	12.6	16.53	8.6	40.66	21.2	136.4	71.2	4.84	2.5	9.84	5.1
54	14173	232.4	....	197.8	83.4	26.76	11.3	21.53	9.1	48.29	20.4	171.8	72.4	4.46	1.9	7.84	3.3
55	8347	133.8	....	109.55	81.9	18.48	13.8	9.97	7.5	28.45	21.3	97.9	73.2	2.64	2.0	5.77	4.3
56	13033	210.0	....	175.5	83.6	25.46	12.1	18.97	9.0	44.43	21.2	151.9	72.3	4.54	2.2	9.04	4.3
57	14580	240.7	....	205.4	85.4	27.20	11.3	22.51	9.4	49.74	20.7	179.0	74.4	3.87	1.6	8.10	3.4
58	6673	110.4	....	89.25	80.9	15.13	13.7	7.59	6.9	22.73	20.6	79.8	72.4	1.78	1.6	6.02	5.5
59	10007	160.0	....	133.6	83.2	21.13	13.2	12.99	8.1	34.12	21.3	116.7	72.9	3.28	2.1	5.87	3.7
60	11820	189.8	....	158.9	83.7	23.67	12.5	16.62	8.8	40.29	21.2	138.4	72.9	3.92	2.1	7.23	3.8
61	11480	191.8	....	161.5	84.2	22.47	11.7	16.70	8.7	39.17	20.4	140.5	73.3	4.28	2.2	7.83	4.1
62	15860	269.2	....	232.2	86.3	28.82	10.7	25.31	9.4	54.11	20.1	200.5	74.5	6.36	2.4	8.18	3.0

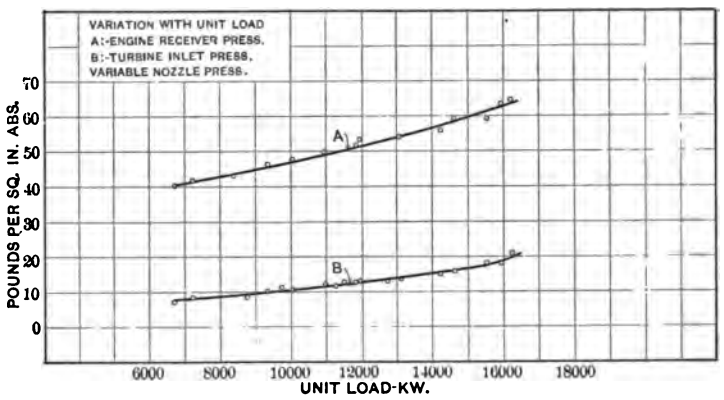


FIG. 20 SERIES E AND F

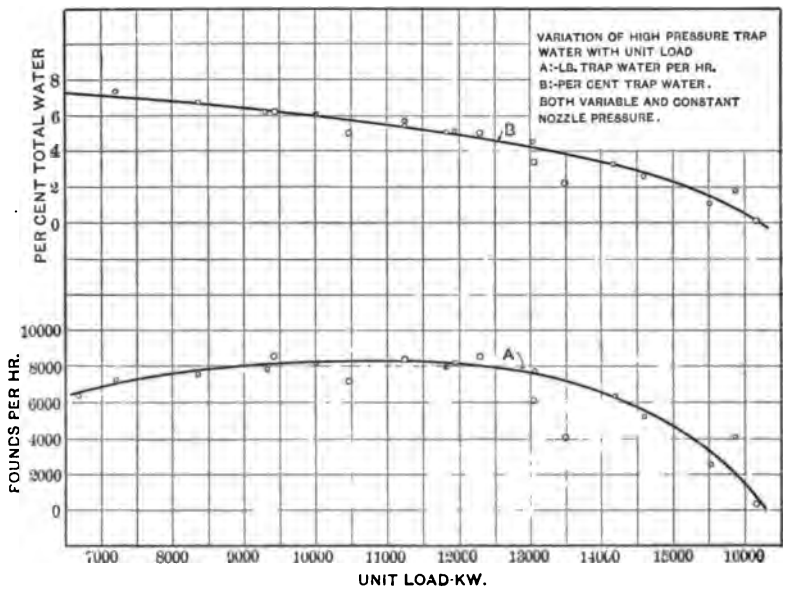
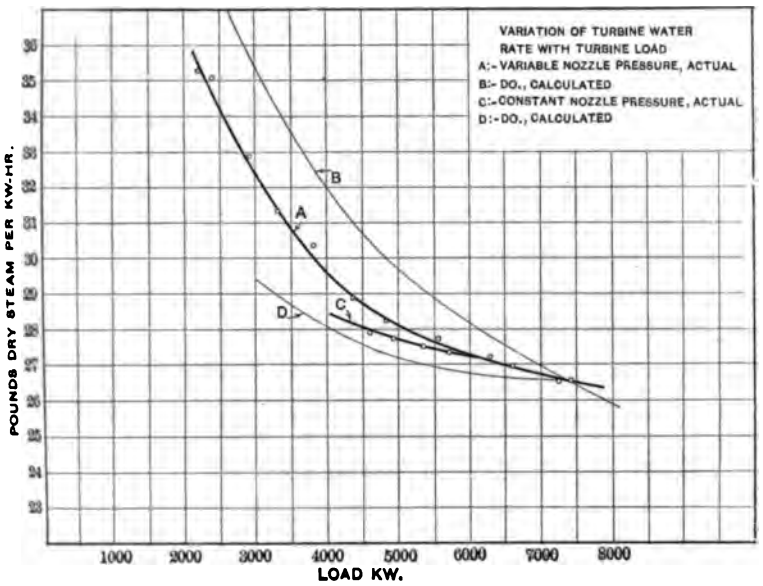


FIG. 21 SERIES E AND F



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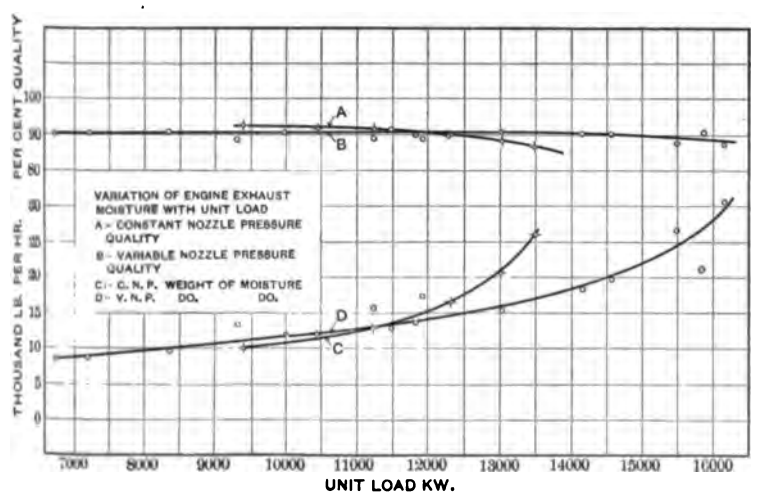

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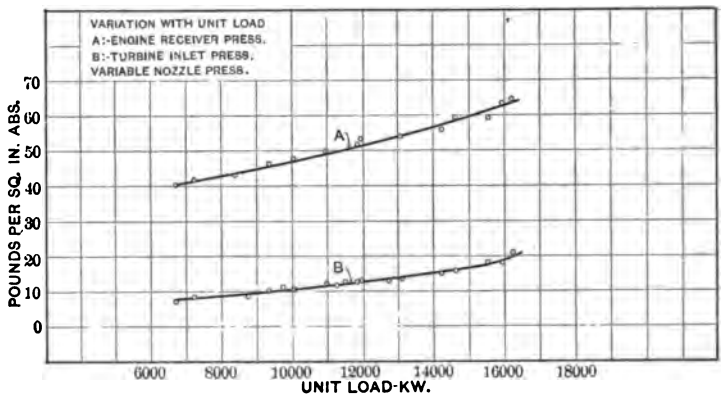


FIG. 20 SERIES E AND F

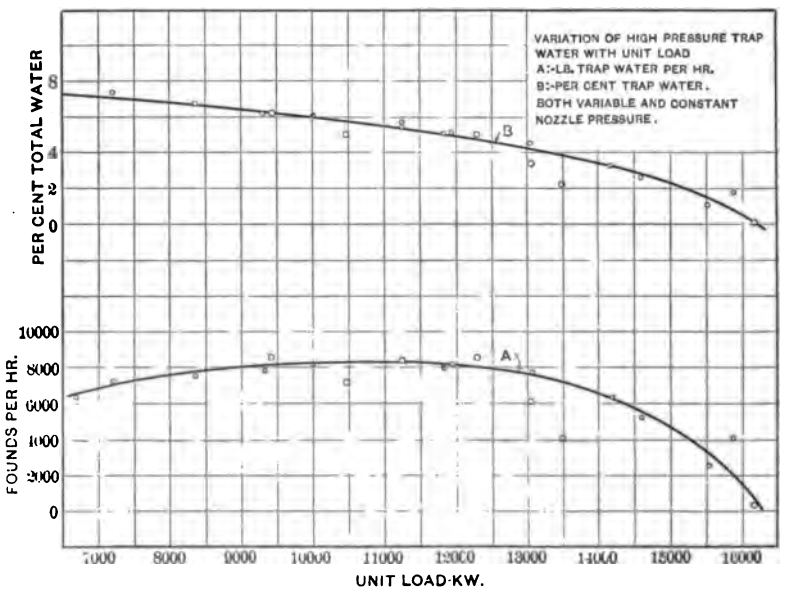


FIG. 21 SERIES E AND F

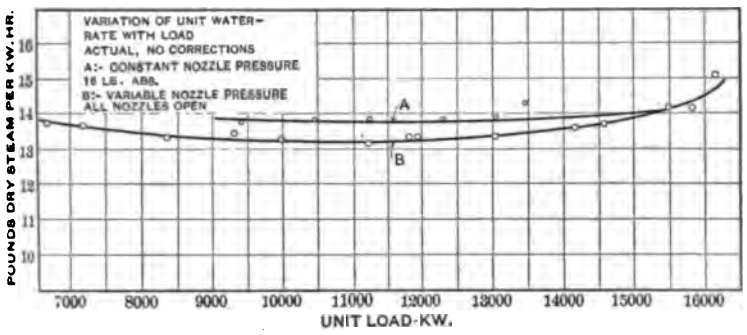


FIG. 22 SERIES E AND F

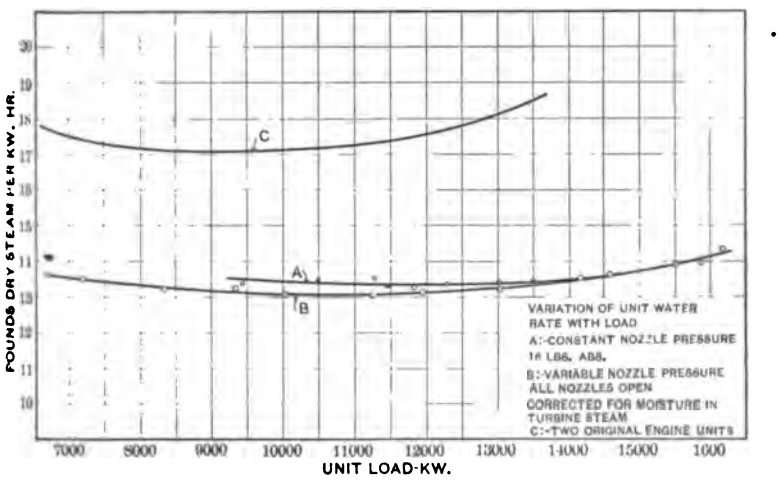


FIG. 23 SERIES E AND F

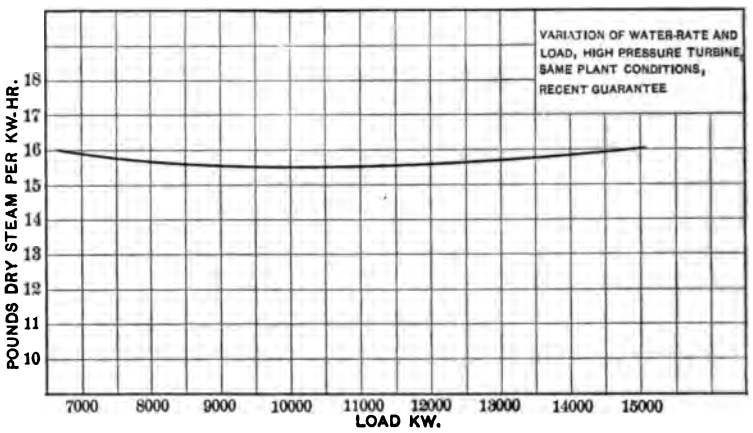


FIG. 23a SERIES E AND F

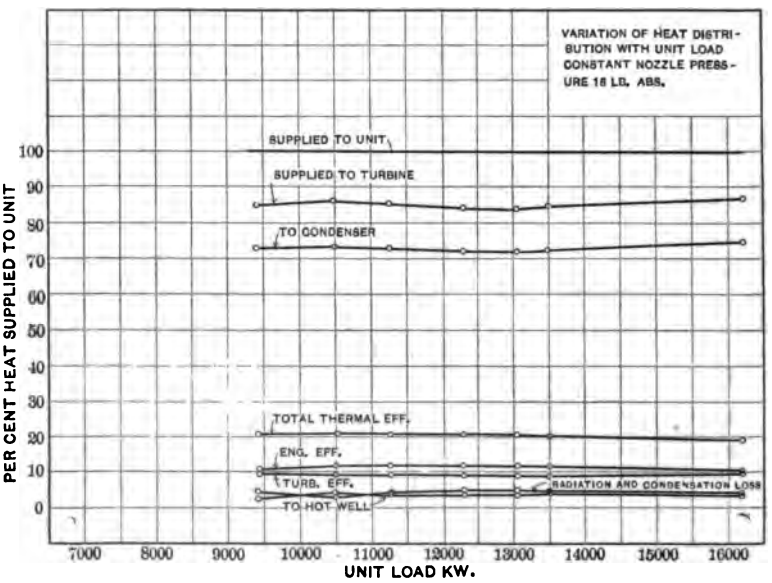


FIG. 24 SERIES E

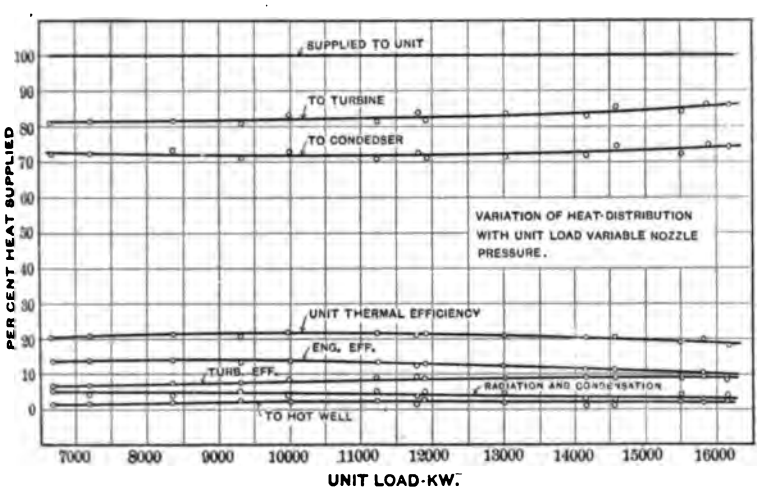


FIG. 25 SERIES F

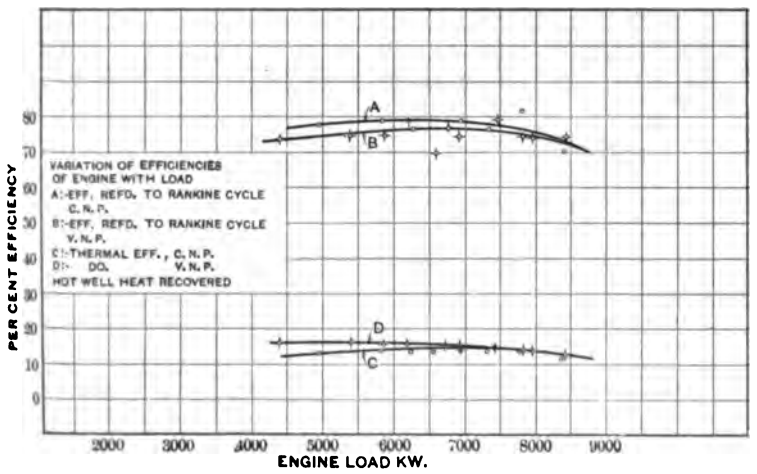


FIG. 26 SERIES E AND F

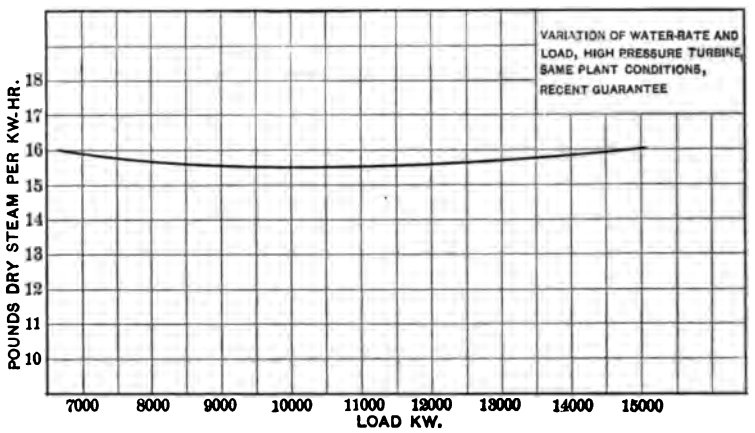


FIG. 23a SERIES E AND F

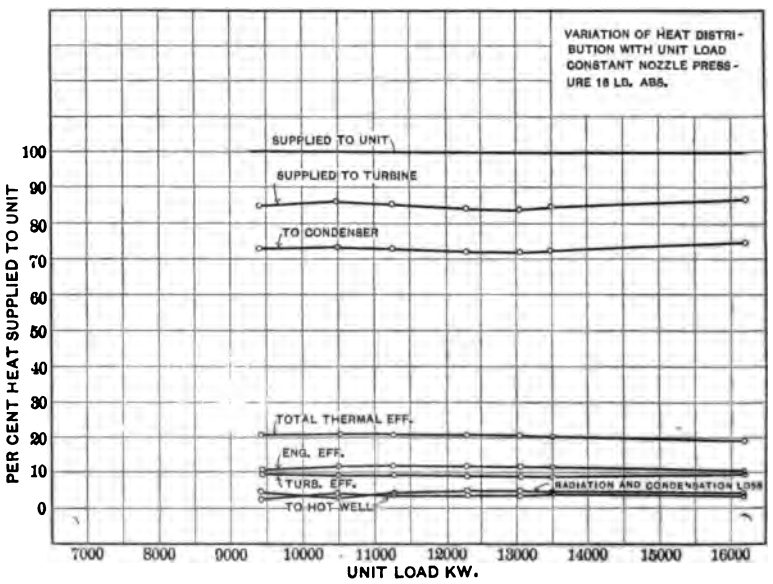


FIG. 24 SERIES E

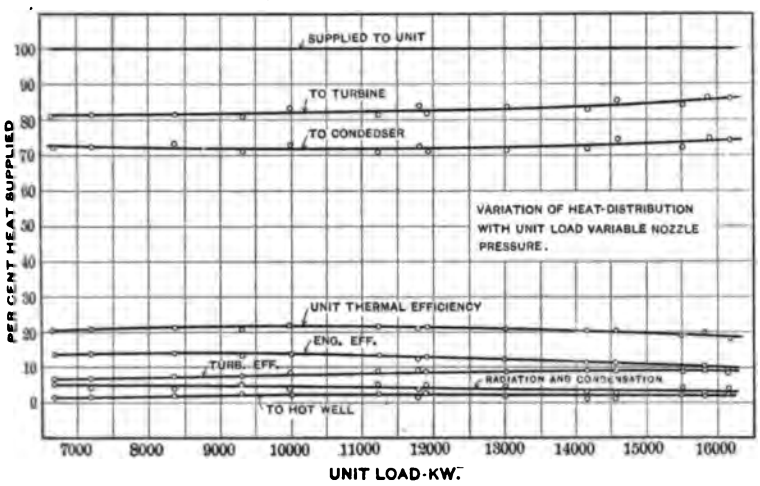


FIG. 25 SERIES F

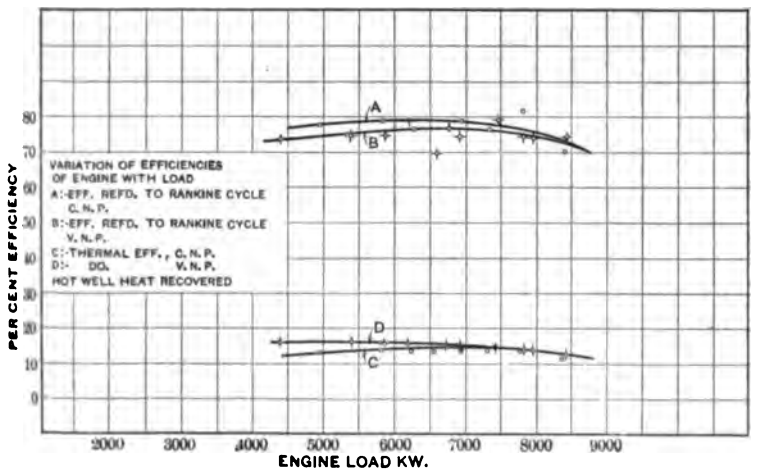


FIG. 26 SERIES E AND F

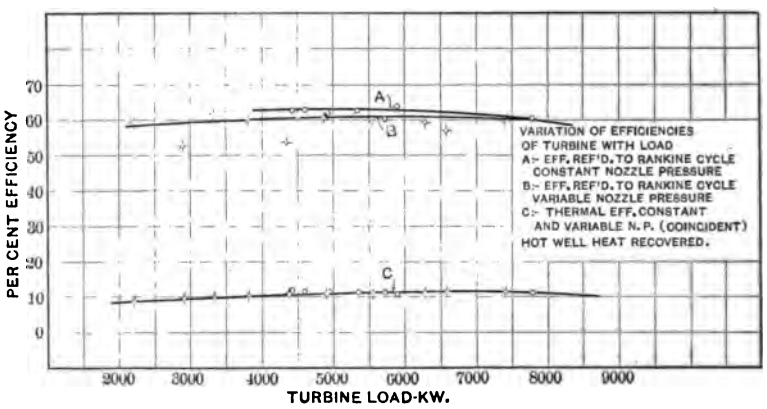


FIG. 27 SERIES E AND F

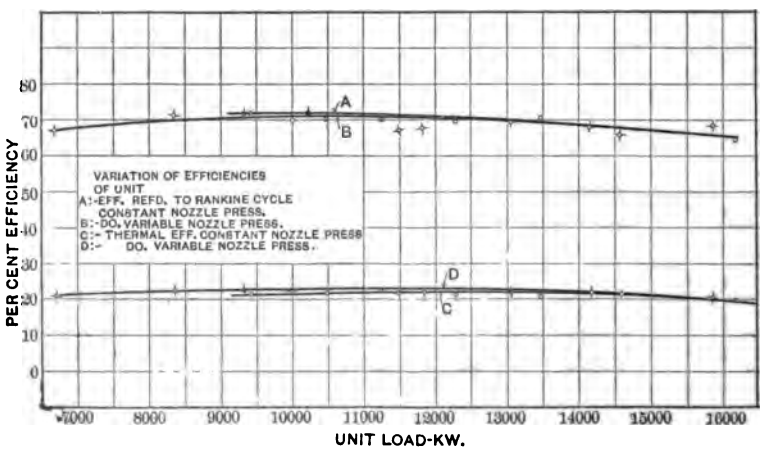


FIG. 28 SERIES E AND F

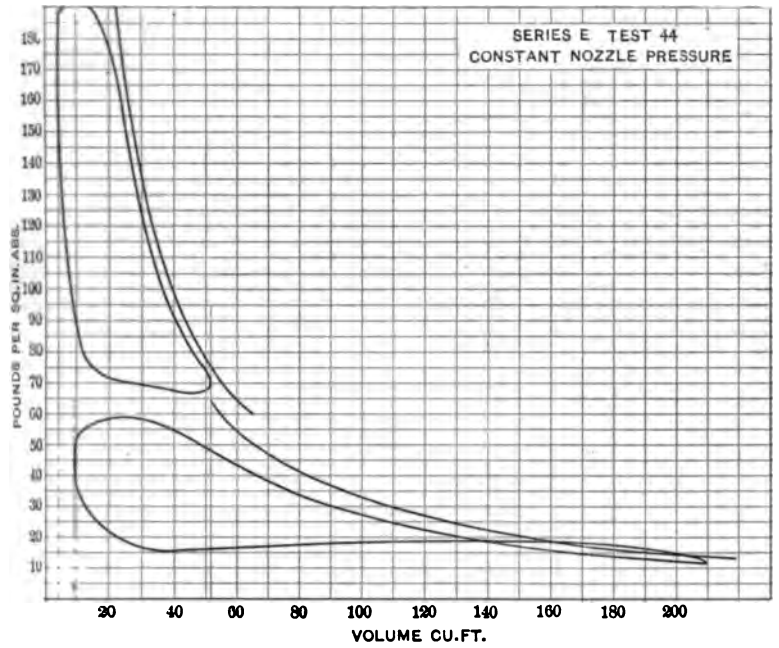


FIG. 29 SERIES E, TEST 44

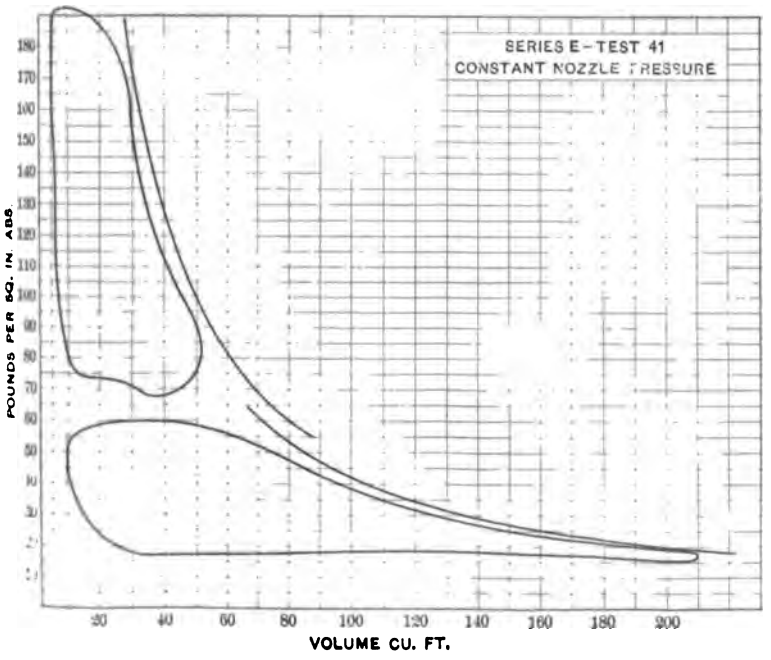


FIG. 30 SERIES E, TEST 41

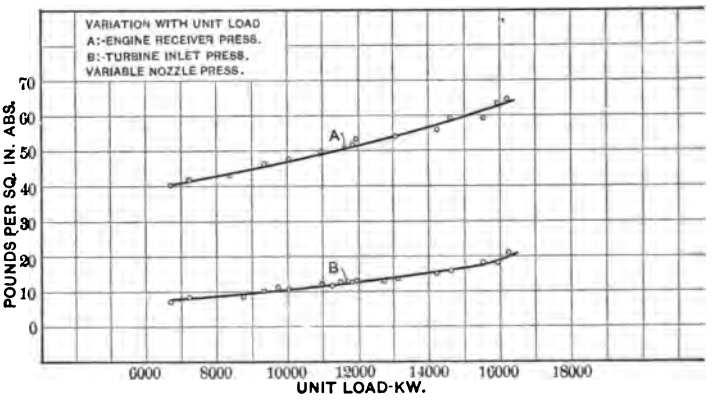


FIG. 20 SERIES E AND F

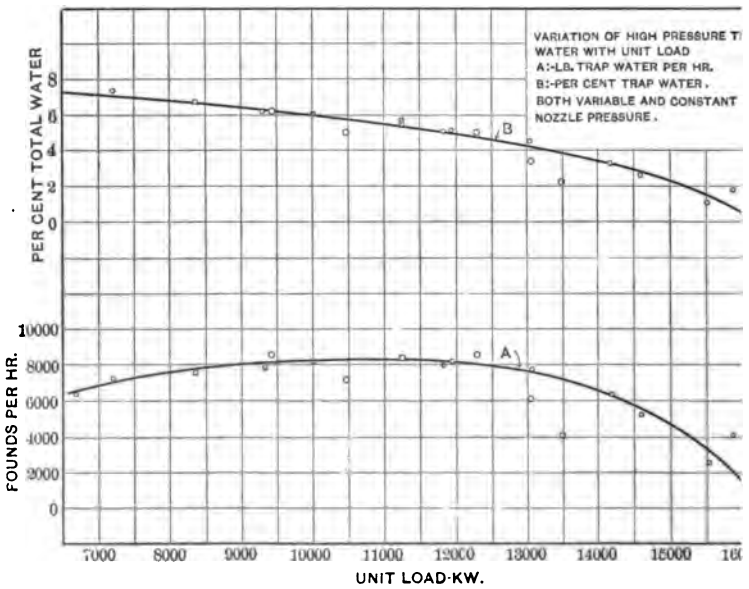


FIG. 21 SERIES E AND F

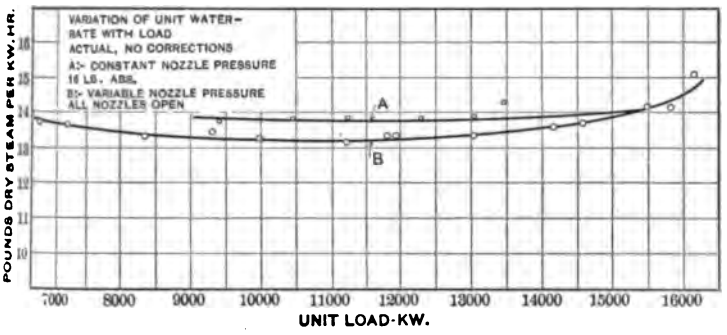


FIG. 22 SERIES E AND F

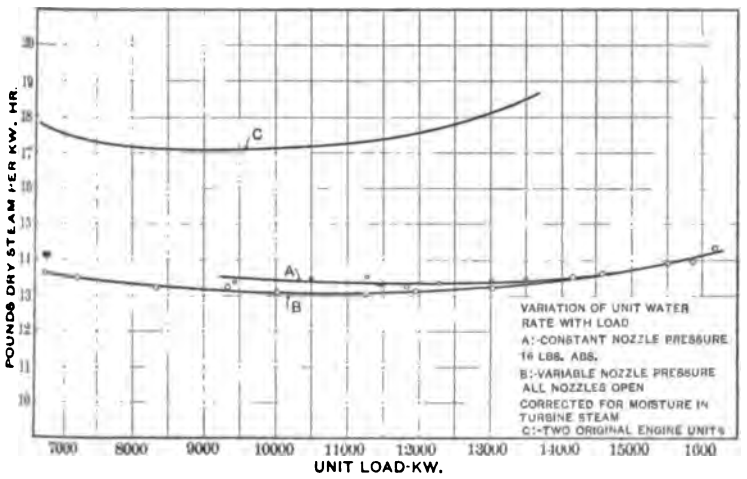


FIG. 23 SERIES E AND F

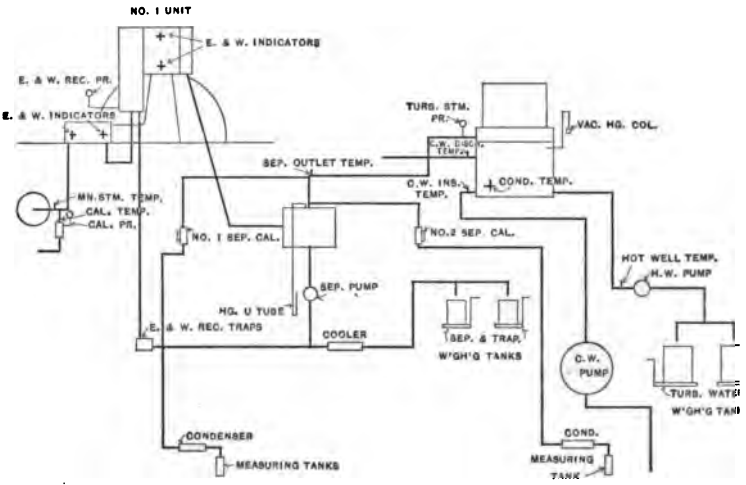


FIG. 35 SERIES C, DIAGRAMMATIC TEST LAYOUT

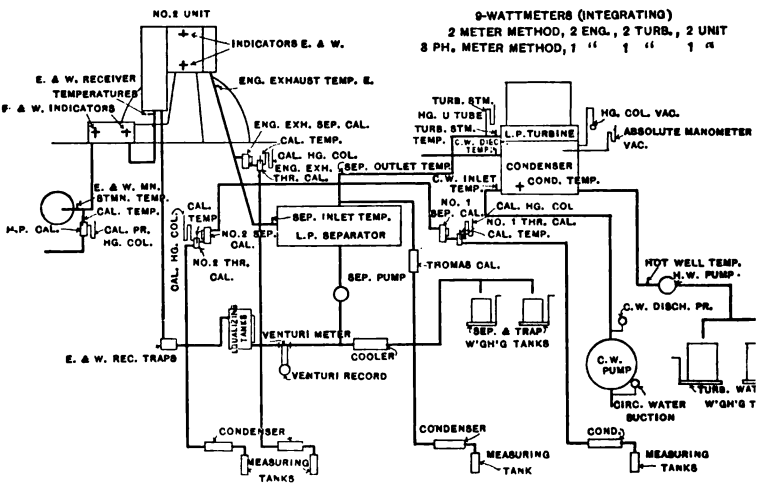


FIG. 36 SERIES D, E AND F, DIAGRAMMATIC TEST LAYOUT

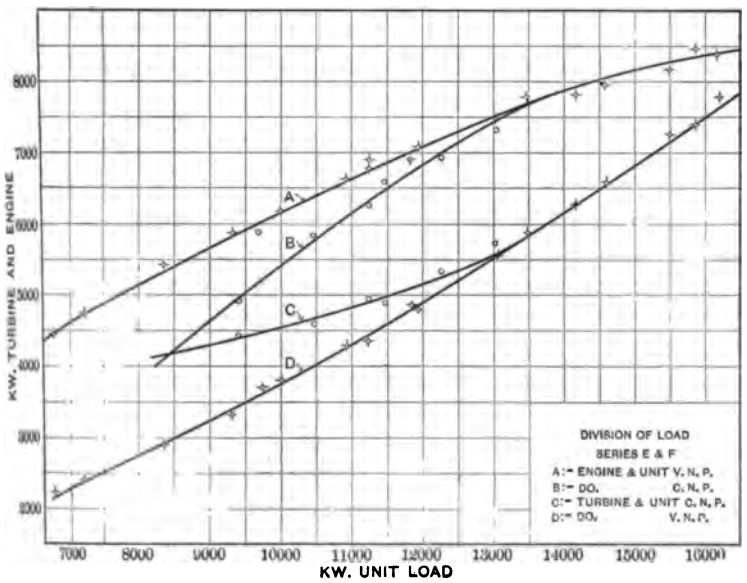


FIG. 37 DIVISION OF LOAD, SERIES E AND F

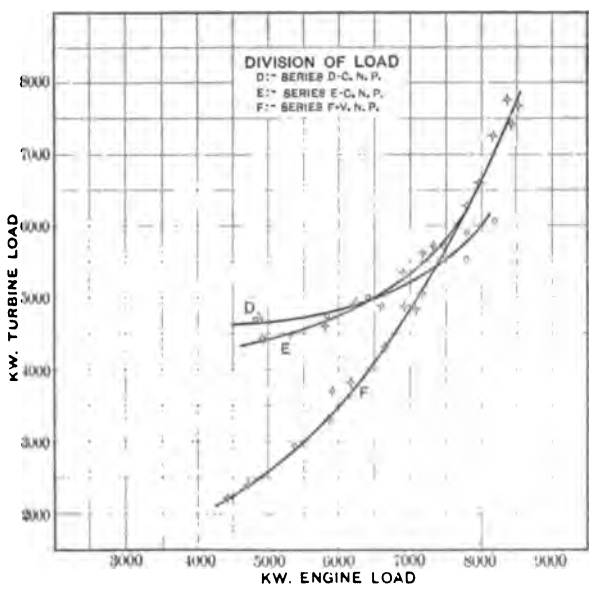


FIG. 38 DIVISION OF LOAD, SERIES D, E AND F

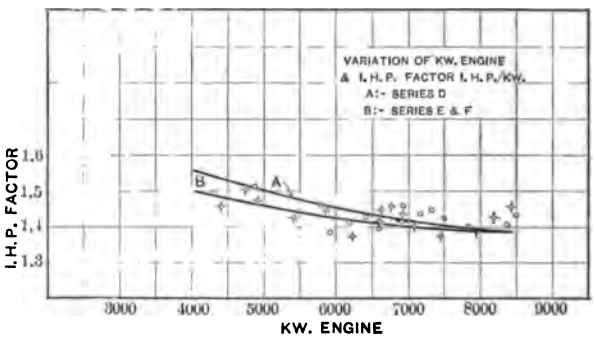


FIG. 39 VARIATION OF KW.-ENGINE AND I.H.P. FACTOR

DISCUSSION

W. L. R. EMMET. The operation of stations by turbines alone is simpler and generally more economical than that of stations which use reciprocating engines and there are many cases where it might be better to install high-pressure turbines instead of coupling low-pressure turbines with existing reciprocating engines. The results shown in Mr. Stott's paper, however, should demonstrate to many station managers that they cannot afford to run reciprocating engines alone when such an improvement can be accomplished by the addition of low-pressure turbines. I regret that Mr. Stott has not dwelt at more length upon the saving in investment and operation which has been effected by this installation, although his tests and explanations afford most of the data necessary for such comparisons. The increase of firing capacity due to the changes made in many of the boilers sometime ago has also contributed greatly to the remarkable improvement in this plant. Comparisons of the original conditions with the ultimate development of the present plan afford a very striking example of what can sometimes be done with an old station.

The results in steam consumption shown by Mr. Stott's tests are very decidedly better than the best results ever accomplished with turbines alone, the advantage in water rate amounting to about 2 lb. per kw-hr. as compared with the best turbine results. While it is possible that this station will never produce power commercially more cheaply than the best modern turbine stations are now doing with equal fuel, the great value of this installation will be apparent when the enormous investment saving is considered.

Some of the curves given in the paper would seem to indicate that the results accomplished by the turbines were inferior to those guaranteed or expected, whereas in fact all guarantees and expectations have been rather exceeded. The reason for this apparent discrepancy is that Mr. Stott has not made allowance for the losses introduced by the presence of moisture in steam entering the turbines, whereas the guarantees on the turbines were based upon dry steam. Mr. Stott has reported the facts as they exist and as they are influenced by such methods of moisture separation as he has used. If

the separation were more perfect the turbine results as shown by the curves would be much better and it is probable that with more experience, an almost complete absence of moisture in the turbine steam can be provided for.

MAX ROTTER. One matter of practical interest is the elimination of the moisture and oil from the steam during its passage from the engine exhaust to the turbine inlet. Tests 45 to 62 seem to show that the moisture remaining in the steam, as it entered the turbine, amounted to an average of over 4 per cent. Can it be assumed that this may be reduced to zero without re-heating or increased pressure drop? If not, then the inefficiency of the separation must be considered as one of the losses inevitable in an installation of this kind, and corrections for moisture entering the turbine should properly be omitted, as such losses would be on a par with the losses in the low-pressure stages of a high-pressure turbine, due to the water of liquefaction delivered to them from the high-pressure stages. It is not the same as a correction for moisture in the steam as originally delivered to the engine, for the engine and low-pressure turbine, with their necessary connecting elements, must be considered as a single unit and it is proper to correct only for conditions due to the imperfection of external apparatus serving the unit. For instance, while a correction for moisture in the steam would be made in testing an engine as a unital piece of apparatus, no such correction would be made in testing, as a unit, the complete plant of such engine and its boilers. The correction of 1 per cent in consumption per 1 per cent of moisture delivered to the turbine is the usual full allowance for the internal losses caused by such moisture; as obviously no deduction of the moisture itself can be made, this having been already allowed for in determining the dry steam delivered to the engine. This correction of 1 per cent is thus equivalent to the customary correction of 2 per cent in consumption per 1 per cent of moisture, as applied to a high-pressure turbine performance. The elimination of oil probably has a greater effect on the maintenance of the efficiency of the turbine and surface condenser than of the boilers.

One of the most interesting features of the paper is the comparison of this engine and low-pressure turbine installation with an installation of high-pressure turbines. It is not clear whether the high-pressure turbine referred to by Mr. Stott is one of a capacity equivalent to that of the low-pressure turbine only, or to that of the combined engine and low-pressure turbine unit. The latter would certainly be proper and seems to be that considered by Mr. Stott in

his statements regarding relative costs (Par. 11); but the high-pressure turbine efficiencies stated in Par. 40d and Fig. 23a, Series E and F, are apparently those of a considerably smaller machine. Nor is it quite proper to compare the efficiencies of two units on the basis of the test performance of one as against the guaranteed efficiencies of the other. A business man will not guarantee more than necessary, nor will he guarantee under any circumstances the best he can hope to do under test. Furthermore, a slight change in operating conditions might materially affect such a comparison. For instance, the majority of modern high-pressure turbine plants operate with some superheat, of which the high-pressure turbine can take greater advantage than can the engine and low-pressure turbine unit. The frequency of the turbo-alternator, in so far as it determines the speed of the turbine, will also exercise some influence upon the results. At the 59th Street station the slow speed of 750 r.p.m. is somewhat unfavorable to the turbine. A higher turbine speed would, in the case of the engine and low-pressure turbine unit, increase the efficiency of the turbine only; that is, the improvement in efficiency would apply only to about one-half of the total load of the unit; whereas, in the case of a high-pressure turbine of a capacity equivalent to that of the combined unit, the improvement in efficiency would apply to the full output of the machine. The comparative operating expenses must also be considered, and these are unquestionably lower for the high-pressure turbine than for the combined unit.

For the purpose of comparing the steam consumptions of the two types of apparatus, the final results given in Table 12, Series E and F, have been replotted herewith on Fig. 40 and curve A drawn through the points. This curve therefore shows the steam consumption of the combined unit, corrected to dry saturated steam at the engine throttle at 180 lb. gage, dry saturated steam at the low-pressure turbine throttle at variable pressure, and a vacuum equivalent to 28½ in. referred to a 29.92 in. barometer. Curve B refers to a high-pressure turbine unit operating with dry saturated steam at 180 lb. gage and a vacuum of 28½ in. referred to a 29.92 in. barometer, at a speed of 750 r.p.m., and having a capacity about equivalent to that of the combined engine low-pressure-turbine unit. This latter curve shows the steam consumptions it would be perfectly safe to expect from such unit under test, and it is probable that a consumption 0.3 to 0.4 of a pound lower would be attained. In making guarantees, from 1 to 1½ lb. per kw-hr. would be added. A comparison of these curves would indicate that the average difference of 8 per cent

as given by Mr. Stott in Par. 14 is ample, and 13 per cent as giv
by him in Par. 40d too high.

To indicate the effect of a change in operating conditio
curves A and B (Fig. 41 herewith) have been plotted to show the pe
formance of the units when operating under the conditions abo
mentioned, except that the steam is superheated 100 deg. fahr.
will be noted that the advantage of the combination as against t
single unit is materially lowered.

That the high-pressure turbine consumptions, as shown by t
curves, are reasonable is proved by a recent unassailable test of t
type of turbine, with steam at 180 lb. gage, superheated 100 de

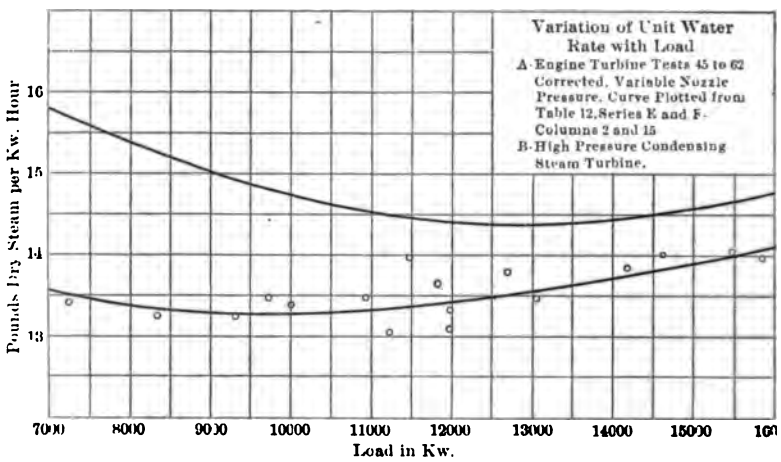


FIG. 40 RESULTS IN TABLE 12, SERIES E AND F

fahr., and a vacuum of 28½ in. referred to a 29.92 in. baromet
which showed a consumption of 14.02 lb. per kw-hr.; the turbi
having a normal capacity of only 4000 kw. at 1800 r.p.m.

An improvement in efficiency of 13 per cent in the 59th Stre
plant would seem almost to warrant a combined engine and low-pre
sure turbine unit as an initial installation, and it would be interesti
to learn whether Mr. Stott would consider such an installation f
extensions of this plant beyond the capacity obtainable by addi
low-pressure turbines to all of the existing engines.

The conditions for which low-pressure turbines are being co
sidered have multiplied much more quickly than anticipate
For instance it has been proposed to operate a turbine by mea

of steam from natural geysers, which is perfectly feasible. The steam would be obtained by passing the hot water through vessels in which a pressure drop would take place and part of the water be evaporated. With such an arrangement it would be necessary to handle 30 to 50 lb. of water to obtain 1 lb. of steam at a pressure slightly below atmosphere.

Another use for low-pressure turbines is that of generating power from hitherto wasted industrial steam. For instance, a turbine is now being installed in an automobile tire factory where the retorts used for vulcanizing are filled with high-pressure steam for a certain period, the major portion of this steam being then blown out

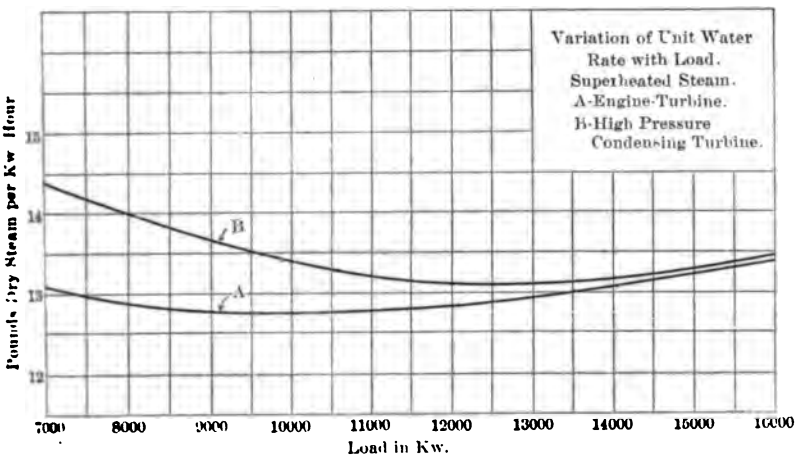


FIG. 41 CURVES A AND B, SHOWING PERFORMANCE OF UNITS WHEN OPERATING UNDER GIVEN CONDITIONS

into the air before the retorts are opened for re-charging. This steam will henceforth be collected in a receiver, in which its pressure will drop approximately to atmospheric, and from which it will be delivered to a low-pressure turbine for use. The supply of steam is almost constant and will generate 1000 to 1200 kw., the only cost being the fixed charges, labor, and the water required for condensing.

Every improved method or appliance is exposed to the danger of being retarded in the progress it really merits by a few ill-advised applications, and there are conditions under which it would be better not to advocate low-pressure turbines as additions to reciprocating engines. In almost all instances figures will show a saving of steam as achievable by such combination, but the cost of power production

in a great many industrial plants is so small an item compared wit the other expenses, that a reduction of even 25 per cent in fuel co sumption is frequently insignificant when weighed against other co siderations.

A low-pressure turbine should not be installed where its stea supply depends upon an old and unreliably decrepit engine. Th proper thing here is an independent high-pressure condensing tu bine. And as a high-pressure condensing turbine of the same ca acity as the engine and low-pressure turbine combined will give nearly the same efficiency as the combination, the boilers and the co densing apparatus will cost about the same for either installatio the fuel consumption will be about the same, and the engine can set aside for emergency use.

There are numerous instances where compound engines are n overloaded but underloaded. Many of them are running non-co densing and it is a condenser and not a low-pressure turbine that needed. The beneficial effect of adding a condenser to an unde loaded compound engine is two-fold: firstly, it will lower the mea effective pressure at which the engine attains its best efficiency an therefore, if the engine is underloaded, it will bring the point of be efficiency nearer the running load; and secondly, there is th increased efficiency directly due to condensing.

The installation of a low-pressure turbine may also be a doub ful expedient in a plant which is being electrified and in which th engine is belted or coupled to a lineshaft so that the direct load is d creasing while the electric load is increasing. Of course a generat could be added to the engine, and a low-pressure turbine run in co nection with this; but beyond the combined capacity of these it wou become absolutely necessary to install a new unit. . Under such ci cumstances the best course would be the installation of a high-pre sure condensing turbine to start with.

E. F. MILLER. I recently made some calculations upon th economy of the low-pressure turbine and found in figuring ov some of the tests quoted an apparent efficiency of 76 to 80 per ce of that obtained from the non-conducting engine. I also worked u the efficiencies and steam consumption of the Rankine engine usi dry steam at a pressure of 15.6 lb. and exhausting at 28-in. vacuu The same calculations were made at other pressures down to abo 6 lb., as shown in Table 15. Taking the efficiency of the generator 83 per cent and the mechanical efficiency of the engine as 90 per cer the steam consumption per kw-hr. was obtained.

Assuming the ratio of efficiency of the low-pressure turbine to that of the non-conducting engine as 63, 67.5 and 72 per cent, the steam consumptions per kw-hr. were calculated. Table 15 affords a simple means by which steam consumptions may be compared.

TABLE 15 STEAM CONSUMPTIONS OF LOW-PRESSURE TURBINES AT VARYING PRESSURES

Abs. Press. at Entrance	Temp. at Entrance deg. fahr.	Abs. Press. at Exit	Temp. at Exit deg. fahr.	Quality of Steam at Entrance	Quality of Steam at Exit	Thermal Eff. of Non-Cond. Eng. per cent
15.60	215	1.005	102	1.000	0.8785	15.93
14.13	210	1.005	102	1.000	0.8827	15.38
11.53	200	1.005	102	1.000	0.8916	14.23
9.34	190	1.005	102	1.000	0.9007	13.03
7.51	180	1.005	102	1.000	0.9125	11.75
5.99	170	1.005	102	1.000	0.9203	10.48

Abs. Press. at Entrance	Steam per h.p-hr. of Non-Cond. Eng. per cent	Steam per kw-hr. of Non-Cond. Eng. Calling Mechanical Eff. of Eng. 90 per cent and Eff. of Generator 93 per cent	Steam Consumption per kw-hr. of Low-Press. Turbine Assuming Ratio of Act. Eff. to that of Non-Conducting Eng. as 63, 67.5 and 72 per cent		
15.60	14.72	23.55	33.6	31.4	29.4
14.13	15.23	24.36	34.8	32.5	30.4
11.53	16.50	26.40	37.7	35.2	33.0
9.34	18.09	28.94	40.1	38.6	36.2
7.51	20.13	32.20	46.0	42.9	40.3
5.99	32.66	36.26	51.8	48.3	45.3

EDWARD L. CLARK. A number of cases have arisen where mills driven mechanically have desired to increase their power by the use of low-pressure turbines. The introduction of the low-pressure turbine in such places is accomplished in a novel and effective manner by tying the electric load and the mechanical load together by means of a synchronous motor or generator. The synchronous motor may either be belted or coupled direct to the main lineshaft driven by the engine, and then electrically interlocked with the generator connected with the low-pressure turbine. With this method, the low-pressure turbine requires no governor and merely delivers power in proportion to the quantity of steam exhausted by the engine.

It is important in the selection of a low-pressure turbine that it should be capable of utilizing the entire engine exhaust. In this arrangement, the turbine may be regarded as the low-pressure cylin-

der of a triple-expansion engine, and manifestly a proper ratio betwe
the low-pressure turbine and engine cylinders should be chosen.
this feature is not observed, the expansion of the steam will not
efficiently carried out or there will be free escape of a part of the stea
through the relief valve between the engine and turbine. Howev
a properly selected turbine will pick up the electrical load and t
surplus power that it is delivering will go through the synchrono
motor, thereby lightening the load of the engine. When the engi
is thus relieved of a portion of its load, it naturally gives less stea
to the turbine until the whole system automatically balances b
tween the mechanical load and the electric load.

An important feature of operating the low-pressure turbi
without a governor is that vacuum comes back on the engine at
loads, the amount of this vacuum being proportional to the amou
of load carried by the turbine. By thus varying the inlet pressures
the turbine and maintaining them below atmospheric pressure, loopi
of the low-pressure card on the engine at light loads is avoided a
the low-pressure valves operate smoothly and without noise at
loads. At the same time, both the engine and turbine run in co
bination at maximum efficiency through their entire range, and t
curves obtained are about as straight as the one in Mr. Stot
test.

It will be seen that the flexibility of such an outfit is independe
of the mechanical load and the turbine can accomplish practica
anything that a high-pressure turbine can accomplish. The ga
in power with the synchronous motor system amounts to nearly 1
per cent, due to the fact that the increased rating of the non-conde
sing engine over what it is at best economy condensing is appro
imately 20 per cent, which should be added to the 80 per cent ad
tional power given by the low-pressure turbine.

Assuming that an engine running under 125 to 130 lb. pressu
consumes per indicated horsepower 15 lb. steam, condensing, and 21
non-condensing, and if we divide the additional steam required wh
running non-condensing by the kilowatts obtained from a low-pr
sure turbine, we obtain a kilowatt for very close to 12 lb. additio
steam per kw-hr. This must be compared with a water rate of a
20 lb. on a high-pressure turbine under the same steam conditio

An interesting point is that the economies obtained for t
combined engine and turbine would be equivalent to a consumpti
of about 11 to 11½ lb. per indicated horsepower in steam engine pra
tice, so that we better the engine economy over what it is at its be

point when run condensing, besides producing a kilowatt for less steam than in a high-pressure unit.

In the majority of cases the low-pressure turbines have been installed in plants having from 125 to 140 lb. of steam, and the relative gain is just as marked as in the stations carrying 195 lb. of steam and high degrees of superheat.

E. D. DREYFUS. It is interesting to note the remarkable difference in Rankine cycle efficiency between the engines and the low-pressure turbines. This looks as if there is some opportunity for improvement on the low-pressure turbine. Mr. W. B. Flanders of East Pittsburg, has made quite a study of turbine efficiencies, and has found that a high-pressure complete-expansion turbine operating with 175-lb. steam pressure and 100-deg. superheat will give the same Rankine cycle efficiency as a low-pressure turbine at the same vacuum and using dry saturated steam.

The gain in economy of 13 per cent, as stated by Mr. Stott, is what would be expected when we consider that this unit is operating on dry and saturated steam. I must, therefore, differ with Mr. Rotter, as I know of no complete-expansion economies on record that do not agree in the main with what Mr. Stott has brought out. A Rankine cycle efficiency of 70½ per cent is possible on a complete-expansion machine, but no turbine performance reaching this degree of efficiency has to my knowledge been recorded in this country. Some have gone as high as 67.8 per cent, but as far as I am able to learn, no record of a complete-expansion machine has exceeded 70 per cent.

I am very much interested in observing the results obtained with constant and variable exhaust pressure. When this question first came up in low-pressure turbine work, variable exhaust pressure was looked upon with disfavor by some designers and engineers, while others advocated this method because of the better results obtained with it. It is now quite evident that in the neighborhood of 5 per cent additional economy is obtained by running with variable exhaust pressure (Fig. 42). As Mr. Stott has stated, it is obvious that unless the piping and apparatus between the engine and turbine are in very good condition, good vacuum will not obtain. I find, however, that there are a number of low-pressure turbine installations where the low-pressure turbine is coupled with two or more compound Corliss engines with moderately long connections, and they secure a vacuum in the neighborhood of 28½ or 29 in. The overall economy,

even in the small 1000-kw. units, indicates the same relative gain as shown by Mr. Stott's results. Fig. 10 and Fig. 11 show the desirability of variable-pressure operation on account of looping of the cards.

Mr. Stott mentioned in the first part of his paper that the maintenance account of a complete gas-engine plant would be from four to ten times that of a turbine station. To the best of our ability in

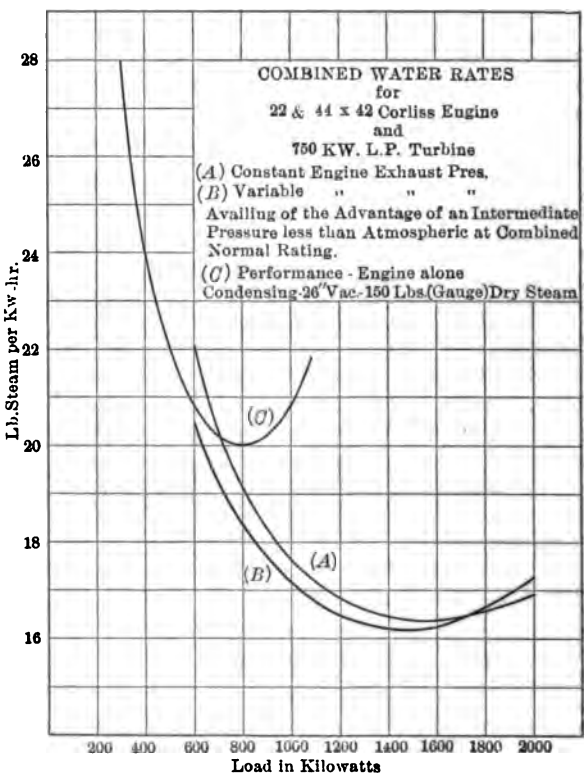


FIG. 42 CURVES OF COMBINED WATER RATES

collecting information and judging working conditions, we do not find it comes up to this factor, and the same thing is true in England according to a paper presented before the Institution of Electrical Engineers on November 17, 1908. This paper was very thoroughly discussed at London, Dublin and Manchester, both favorable and adverse comment being made, but the prevailing opinion seemed to be that the maintenance cost of the complete gas plant would not

much exceed that of the steam turbine plant; in fact, the author of this paper claimed it to be the same. When the producer and boiler are considered, there is reason for this statement.

Regarding the statement that the results obtained closely approach gas-engine efficiencies, gas-engine coal consumption is usually given for 12,000 to 13,000-B.t.u. coal, but considering 14,500-B.t.u. coal in both steam and gas plants, a material difference of 20 to 25 per cent will easily be obtained in favor of the gas equipment over the most efficient steam machinery.

The value of the low-pressure turbine is rapidly bringing about its extensive use in connection with the gas engine, employing the waste heat of the jacket and exhaust.

CHARLES P. STEINMETZ. The paper deals with a combination of the low-pressure steam turbine with the induction generator, which, while possibly not familiar to some, is assuming a very high industrial importance.

The electrical part of the unit, the induction generator, is not a new type of machine. Its existence was known and its characteristics and behavior investigated and discussed many years ago; but only now has the industry developed in such a manner as to give conditions in which the induction generator is preferable to the synchronous generator.

There are two kinds of alternating-current generators: the synchronous generator, which is the ordinary alternating-current machine with which we are familiar, and the induction generator. Constructively, the stator or stationary structure of both types of alternator is practically the same. It comprises a polyphase winding, in which the electromotive force is induced by the rotating magnetic field, arranged in a laminated structure. The difference between the synchronous generator and the induction generator is in the rotor. In the synchronous generator this is a revolving magnetic field excited by direct current; while in the induction generator it contains a short-circuited winding the same as the armature winding of the familiar induction motor. From this variation results the difference in the production of the magnetic field which by its rotation induces electromotive force in the stationary generator winding. The magnetic field of the synchronous generator is produced by the action of the direct current in the field poles; that of the induction generator is produced by the reaction of the alternating currents issuing from the induction generator. As a consequence

the synchronous generator must run in step with the frequen the alternating system; that is, the rotor must move exactly on for every reversal of voltage in the external system. Conve the induction generator cannot run in step with the frequency must always run faster, exceeding synchronism by an amount de ing upon the load, so as to cause the induction in the short-circ windings which produces the currents therein. That means synchronizing is not required in the induction generator. Fur more, since the induction generator does not depend upon ru in step with any other machine, the possibilities of see-sawing so-called hunting which may occur in the synchronous machine, not exist with the induction generator.

The difference in the production of the magnetic field of th types of alternating-current generator is the cause of the very acteristic variations in their performance. The magnetic field c synchronous machine, and therefore, the electromotive force inc in its armature, depends on the direct current supplied to its winding, but is essentially independent of the load of the mac It is dependent only in so far as the current output and the p factor modify the field, varying it in the manner expressed b term "regulation of the machine." The induction-motor field i duced by the reaction of the currents issuing from the machine. induction generator, therefore, has no regulation and no mag field independent of the voltage at the terminals and the but the magnetic field of the induction machine is produce the reaction of the currents at a value corresponding to the vc produced at the induction-generator terminals by the synchr machines connected to the same system. The induction gene depends in its magnetic field and voltage on the excitation o synchronous machines in the same system; that is, it can gen only when connected to a system to which synchronous machin also connected, whether synchronous generators, motors, conv or equivalent apparatus. It has no voltage of its own and ca operate on a system on which no synchronous machine is conne

The regulation of such a combined system of synchronous induction machines, therefore, is by the regulation of the synchr machines operating on the system. Any change of load varie voltage as it would be varied if this change of load occurred o synchronous machines in the system. The induction genera merely a machine feeding electric power into the system bu participating in the voltage regulation or voltage control and h

no direct effect on the voltage. While the synchronous machine at open circuit has a terminal voltage, the induction generator ceases to generate and has no voltage at its terminals at open circuit if it is disconnected from the alternating system. In a synchronous generator, even when short-circuited, the electromotive force continues to be induced in the armature windings because the magnetic field is still there as produced by the direct current. The synchronous generator therefore has a short-circuit current which may be many times full-load current, since the total induced electromotive force must be consumed inside of the synchronous generator armature. An induction generator, when short-circuited, has no voltage at the terminals, and therefore receives no current, has no magnetic field, and ceases to generate. In the induction generator when short-circuited, the current dies down from its previous normal value to zero at a rate depending on the resistance and inductance of the internal circuit in just the same manner as the current in a reactive coil, for instance, would die down when the coil is short-circuited and the impressed voltage withdrawn from it. The short-circuit current of the combined system of synchronous and induction generators is therefore only the short-circuit current of the synchronous generators.

There results therefrom also, the characteristic difference that the synchronous generator can generate current of any character (energy, reactive or wattless, lagging or leading) depending on the nature of the system to which it is connected, or the power factor of the supply system; while the induction generator can generate only energy current, and in addition continuously consumes or receives a certain amount of reactive or wattless lagging current required for its excitation. This latter it receives from the synchronous generators or the synchronous motors and converters in the system. The induction generator, therefore, cannot supply alone a general alternating-current system, for instance, a system of light and power distribution, which requires energy current, as well as reactive, or wattless lagging current; and where a combination of synchronous and induction generators is used, all the lagging current of the system must be supplied by the synchronous generators, and in addition the lagging current also consumed by the induction generator for its excitation.

In a system in which there is considerable lagging current, a very large percentage of induction generators is a questionable advantage, since it may throw an excessive overload in current on the synchronous

generators, the latter having to supply all the lagging current. a system requiring no lagging current, or being built to supply lag current, as rotary converters or synchronous motors, which is type of system on which Mr. Stott's generators operate and is u in the large electric power generating and distributing systems, m of 25-cycles, there is no lagging current required because the sy can be run at unity power factor or even at leading current, an synchronous motors and converters can be caused to supply the ging exciting current of the induction generators. There the in tion generator is at its greatest advantage.

The difference may possibly be described by saying the syn nous generator generates electric current while the induction gene electric power. That is, the synchronous generator supplies ele current to the system whether this current is a power current wattless, powerless current; the induction generator can supply power current and no wattless current. The induction gener therefore, is the typical converter from mechanical into electric p It consumes mechanical power and supplies electric power withou pending for its supply on field excitation, speed, synchronism o other feature. It is consequently the ideal machine to float o alternating-current system, by receiving whatever mechanical p is available and supplied to it in a low-pressure steam turbine the exhaust steam of reciprocating engines; or in the hydraulic bine from whatever water power there may be available. It rec the mechanical power and converts it into a proportional amou electric power, at whatever voltage the system happens to ru and at any speed, speeding up just above that for which system is set by its frequency, but with no necessary regula Its straight and simple function is the conversion of one kind of e to the other, separate entirely from the problem of regulation adjustment which is thrown over into the synchronous machin the same system. This is what makes the induction generat simple and convenient apparatus for cases like that described i paper and for all others where mechanical power is to be picke from water powers here and there, and is too small, possibl warrant installation of specific regulating mechanism.

There is an interesting and somewhat unexpected result s by the tests, namely that the efficiency was found higher operating the turbine with varying nozzle pressure than when ating with constant nozzle pressure. The explanation of this is by the curves in Figs. 17 and 18. In the latter the efficiency o

low-pressure turbine is higher for constant nozzle pressure, just as expected, but constant nozzle pressure of the turbine means constant exhaust pressure of the steam engine and with this and the varying load, as shown in Fig. 17, the efficiency of the steam engine falls off, dropping from the maximum point at a rate which is so much greater than the gain in efficiency of the steam turbine that the combined efficiency shows an advantage in favor of varying nozzle pressure. This illustrates the fact that the turbine side is much less sensitive to variations of the operating conditions from its best condition than the steam engine is, and that to get maximum economy in the operating conditions the engine should be favored. But that also throws a side-light on one of the reasons why the Rankine efficiency of the turbine is less than that of the steam engine part, because all the unfavorable conditions of operation must be thrown on the turbine side of the cycle to get maximum average resultant efficiency.

The gain in efficiency due to the addition of the low-pressure turbine is on the lower side of the cycle, because of the ability of the turbine to expand the steam to a pressure lower than the exhaust pressure of the low-pressure cylinder of the steam engine, an extension impossible with the reciprocating engine. The combined apparatus gains in the ability of the turbine to do what the reciprocating engine is not able to do. This must be kept in mind when comparing the low-pressure turbine and steam-engine plant with the high-pressure turbine plant.

The reciprocating engine in general cannot gain by superheat as much as the steam turbine gains, and comparison of the combined efficiency of a saturated-steam reciprocating engine and low-pressure turbine with a high-pressure turbine is not quite fair to the latter, because on the high-pressure side the steam turbine can get an additional gain in efficiency by using superheat which the reciprocating engine cannot to the same extent. In comparing things it is always difficult to get conditions which are equally fair to both types of apparatus because the conditions of proper operation are different in each.

J. W. LIEB, JR. The author is somewhat optimistic in his estimate that it would be possible to realize as much as 20 per cent of the installation cost from the sale of used apparatus. It would probably be necessary to accept a lower figure, but the result, however, would be still more in favor of the installation of the low-prossure turbines.

In the application of the induction generator we have a s
tion of the problem which combines simplicity of construction
operation with a minimum of installation cost. The induction
erator is also of notable assistance in solving the otherwise very
cult problem of handling through the available types of switc
gear the enormous energy which might with the usual types of ap
atus be difficult to handle in case of a short circuit on the bus b

The results of the condenser tests are particularly interestin
account of the high rates of heat transference, considerably in adv
of the results hitherto attained.

The paper is a notable contribution to the economics of po
plant engineering and the apparatus described should serve to
a new lease of life to otherwise antiquated engine-driven equipm
although it would be difficult to find another case where the app
tion could be made with such manifest advantages.

D. S. JACOBUS. I visited the plant of the Interborough C
pany while Mr. Stott's tests were being made and desire to comm
most highly the degree of accuracy observed and the general c
acter of the work.

The economy of all piston steam-engine installations may
be improved as much as 25 per cent by adding a low-pressure turb
By examining the paper on tests made at the plant of the Pa
Light and Power Company at Redondo, California, presente
this Society by Mr. Weymouth[1], it will be found that the heat consu
tion with a steady load with piston steam engines was about 24
B.t.u. per kw-hr. The heat consumption was obtained by divi
the heat of combustion of the oil burned at the boilers by the net
trical output in kilowatt-hours at the switchboard. The effici
in the tests of the combined unit by Mr. Stott is 20.6 per cent b
on the heat in the steam consumed, and if we take the efficiency o
boilers at 76 per cent, a figure obtainable with oil, the heat of com
tion of the fuel burned at the boilers would be 21,800 B.t.u.
difference between Mr. Stott's figures and those obtained at the
ondo plant is, therefore, about 12 per cent. There is a further a
ance for the fact that the steam was superheated about 100
fahr. in the Redondo tests and this would increase the figure
make it come more than 12 per cent. It does not seem possible
the introduction of a low-pressure steam turbine at the Red

[1] Trans., vol. 30, 1908, p. 775.

plant could ever reduce the heat consumption 25 per cent, bringing it down to 18,600 B.t.u. per kw-hr.

The results obtained by Mr. Stott are very close to those which can be secured with large gas engines. The economy of 21,800 B.t.u. could be reduced with proper superheat to about 20,000 B.t.u. per kw-hr., which would be all that could be expected of a producer-gas plant if run on a commercial swinging load with high daily peaks and periods of low power. In a 15 days' continuous test made at the Redondo plant where the load varied daily through a wide range from high peaks to periods where but little load was on the station and where there was a lay-over period of 4½ hours per day, the heat consumption averaged about 25,000 B.t.u. per kw-hr. and it is questionable whether a producer-gas-engine installation could do very much better with a load of this character.

B. R. SHOVER.[1] In regard to the statement that the result obtained with the engine-turbine-unit had closely approached the best efficiency obtained in gas-engine practice, I desire to call attention to the installation of four 2000-kw. units at the Illinois Steel Company, operating on blast furnace gas. Records kept for six months under working conditions show a consumption of 15,000 B.t.u. per kw-hr. at the switchboard. When this result is compared with the 21,000 B.t.u. per kw-hr. at the 59th Street station, the comparison is more in favor of the gas engine than the statement made in Mr. Stott's paper.

D. S. JACOBUS. The 15,000 B.t.u. quoted by Mr. Shover is based on the heat of combustion of the blast furnace gas used by the engines. If there had been a producer this value would correspond to that computed on the basis of the low heat value of the gas, and where allowance is made for losses through all auxiliaries, this figure would have to be divided by about 0.7 to give the heat units in the original fuel. This would give a much higher heat consumption, say, over 20,000 B.t.u. per kw-hr.

G. R. PARKER.[2] The question often arises as to the smallest size of plant in which a low-pressure turbine can profitably be installed, and while no accurate data are yet available, I consider it doubtful if very

[1] Electrical Engineer, Carnegie Steel Co., Youngstown, O.

[2] General Electric Co., Schenectady, N. Y.

satisfactory results can be obtained in plants of less than 300 or kw. This is due to the fact that the actual cost of producing pow small installations is not made up so largely of coal as it is in l installations, the labor and the numerous operating expenses stituting a much larger percentage of the cost.

O. JUNGGREN. The overall efficiency shown by Test Table 8, is 72½ per cent of the total available energy bet the steam entering the engine and the recorded exhaust pressu the turbine. Test 42 shows an efficiency of 69.6 per cent, another, 68.7 per cent under different conditions of load and vac A high-pressure turbine, working under the same conditions of st pressure and vacuum, would probably not give as high an effici over such an available range of load as that given by the comb unit, but a high-pressure turbine of approximately the same could reasonably be expected to give 70 to 70½ per cent at the most economical load, although fractional efficiencies would be as good as for the combined unit. A high-pressure turbine w be considerably cheaper then the combined unit and in the near fu high-pressure turbines will be made having as high an efficiency a combined unit, and still be cheaper than a combination of engine turbine. The vacua obtained in these tests are quite remark and show what can be done in actual practice.

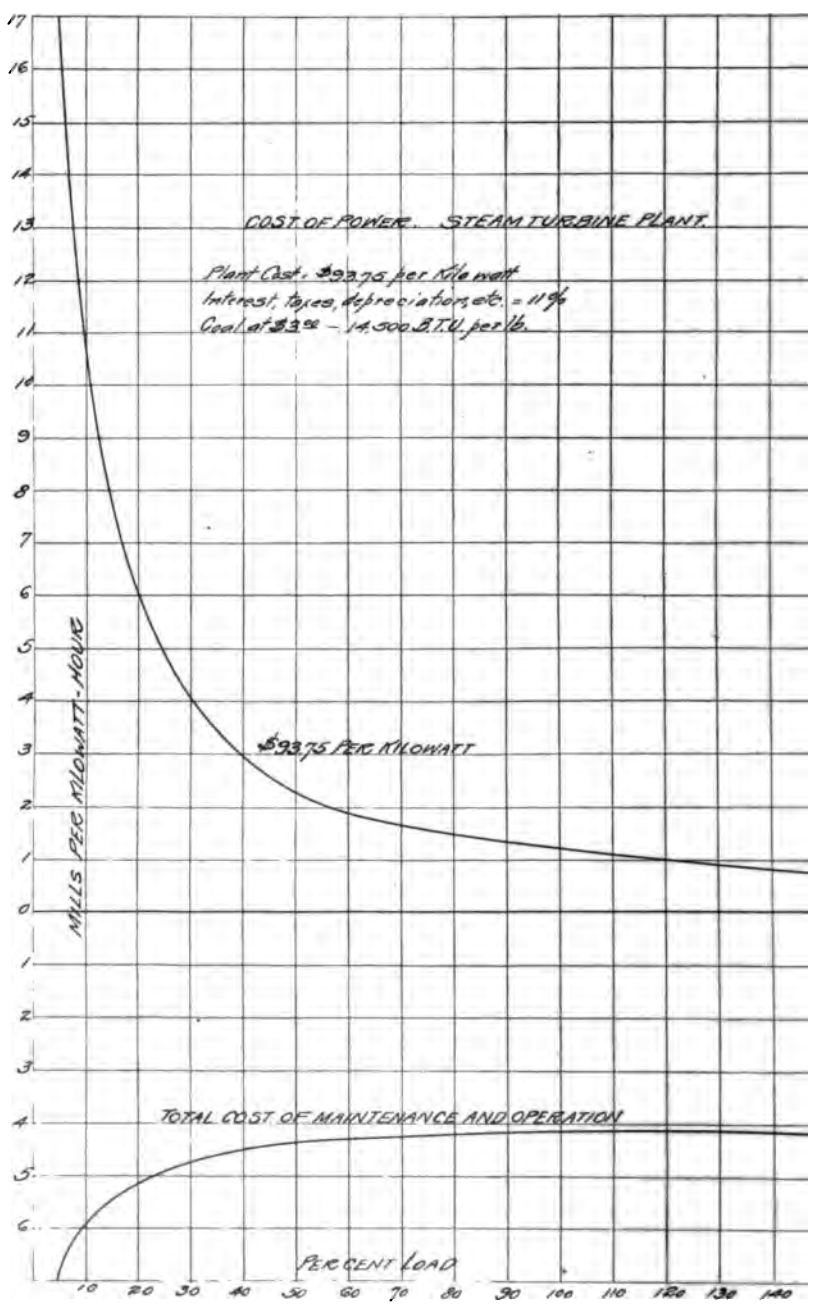
F. SAMUELSON[1] said that low-pressure turbines of various t have been employed in England and all are proving fairly suc ful. The chief difficulty in the installation of these mac has been to meet the Board of Trade regulations as to cons back pressure on hoisting engines. Accidents are sometimes ca by a drop in back pressure at the engine, due to demands the accumulator by the turbine. To prevent this trouble a si automatic valve has been employed between the engine and th cumulator to shut off the supply from the engine when the accumu pressure falls to atmospheric. While the regulating valve is cl the turbine is supplied with steam at a reduced pressure. This works equally well between the turbine and the accumulator, the capacity of the latter is much reduced because of the small sure limit between which it operates. This results in the use of l pressure steam in the turbine on short stoppage of the engine.

[1] Turbine Engineer, British Thomson-Houston Co., Rugby, England.

THE AUTHOR. Refiguring one of the assumed cards (Card C, Table 3, series B) for 100 deg. superheat, we get an actual water rate of 12.9 lb. per h.p. instead of 13.6 with saturated steam, since the missing water and leakage is cut to less than 0.1 of the original value in the high-pressure cylinder. As the missing water in the high-pressure cylinder forms about 0.6 of the total missing water, we shall have 0.46 of the original missing water in this case, or $0.156 \times 0.46 = 0.072$, say roughly 0.08. The B.t.u. supplied per hour $= 12.9 \times 9836 \times 1259 = 159{,}800{,}000$. Radiation and conduction, 1 per cent = 1,598,000 Bt.u.-hr. High-pressure cylinder work $= 5080 \times 2545 = 12{,}940{,}000$ B.t.u-hr. This leaves 145,262,000 B.t.u. in the steam at high-pressure exhaust, or $\frac{145{,}262{,}000}{126{,}900} = 1145$ B.t.u. per lb. At 52.2 lb. absolute, this corresponds to a quality of 96.8 per cent or 3.2 per cent moisture; of this about 2 per cent will be thrown down as receiver drain.

The heat thus removed is $0.02 \times 126{,}900 \times 253 = 643{,}000$ B.t.u., leaving 144,619,000 B.t.u. in 124,360 lb. of steam delivered to the low-pressure cylinder. Low-pressure radiation, $0.01 \times 144{,}619{,}000 = 1{,}446{,}000$; low-pressure work $= 4756 \times 2545 = 12{,}100{,}000$; leaving 131,073,000 B.t.u–hr., or 1065 B.t.u-lb. which at 13.5-lb. absolute exhaust pressure gives a quality of 91.5 per cent, or 113,800 lb. dry steam available for the turbine. This will give 3700 kw. on the turbine, which added to the 6710 kw. on the engine gives 10,410 kw. at 12.18 lb. per kw-hr. as against 14.2 lb. with saturated steam. In actual practice the 14.2 rate was cut down to 13.25, and it is reasonable to expect the same sort of result under superheat.

The reciprocating engine, when designed for superheat, makes just as good use of it thermodynamically as a steam turbine, but will not stand so much superheat. The point has been raised that a moisture correction on the turbine is not fair, since without reheating it is not possible to reduce the moisture in the turbine steam to zero. It is fair in this sense, that in order to compare the various water rates on the same basis, it is necessary to reduce all steam conditions to a standard and that standard is naturally dry steam. Moreover, when the moisture gets as low as 1 per cent or 2 per cent the correction is negligible in amount, and the curve of corrected water rate is substantially true. It is quite possible that a separator can be designed that will take out all but 0.2 or 0.3 per cent of moisture; and in this case the correction justifies itself.


COST OF POWER. STEAM TURBINE PLANT.
Plant Cost. $93.75 per Kilowatt
Interest, taxes, depreciation, etc. = 11%
Coal at $3.00 - 14,500 B.T.U. per lb.
$93.75 PER KILOWATT
MILLS PER KILOWATT-HOUR
TOTAL COST OF MAINTENANCE AND OPERATION
PER CENT LOAD
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1
2
3
4
5
6
10
20
30
40
50
60
70
80
90
100
110
120
130
140

In reply to the question by Max Rotter as to whether it would be advisable to install in a new plant such a combination as described in the paper, the accompanying diagram (Fig. 43), showing the factors entering into the cost of power, will serve as an answer. For example, with a low load factor, it is quite evident that the all-important point is to keep down the fixed charges, for when the load factor is less than 20 per cent, the fixed charges are of vastly greater importance than any possible gain of efficiency due to a better type of prime mover. This is true of any plant, and the curve shows the futility of attempting to carry peak loads by means of gas engines, water power or any other prime mover necessitating a large investment per kilowatt. On the other hand, with loads having a load factor of over 60 per cent, especially where fuel cost is high, the investment factor is of relatively small importance, and the all-important matter is to keep down the maintenance and operating charges by using the most efficient type of plant obtainable, provided that it is at the same time thoroughly reliable.

The total cost of power can be obtained from these curves by simply taking the sum of the ordinates above and below the axis for any load factor desired.

SYMPOSIUM ON ELECTRIC DRIVING IN MACHINE SHOPS

No. 1276*a*

ECONOMY OF THE ELECTRIC DRIVE IN THE MACHINE SHOP

By A. L. De Leeuw, Cincinnati, O.

Member of the Society

It is proposed to show in this paper the most salient points which affect the economy of the electric drive in the shop, and also, in a general way, the proper relation between the motor and the driven machine.

2 When the electric motor was first used in the shop, practically no other claim was made for it than that it saved power by obviating the losses in line and countershafts. Exaggerated statements were made of savings to be effected; and though it was proved later that many of these claims should be divided by a large factor, and that some should even be provided with the negative sign, these statements did a great deal of good by calling attention to the fact that great losses existed.

3 The writer knows of no way to determine the exact amount of these losses, but wishes to call attention to the fact that a method which has been employed quite frequently is entirely misleading. The method referred to is, to measure electrically or by indicator card the amount of power required to run all or a part of a shop with and without machine load. The difference between the two readings is supposed to be the loss. That this is wrong becomes obvious as soon as one considers that the frictional load of every bearing changes with the amount of the load, and that the belt pull sets up bending and torsional strains in long lengths of shafting, which may cause losses much greater than the losses by journal friction.

4 The method of taking separate measurements of the work done by each machine individually, and totaling the result, is also

Presented at the St. Louis and New York Meetings, April 1910, of The American Society of Mechanical Engineers.

wrong, as all machines do not require the maximum amount of po at the same time. To multiply the total by some fractional co cient is merely a refined way of guessing. Statements have fr time to time appeared, as to the amount of saving effected by the s stitution of motor drives for lineshaft drives, but never with positive statement that at the same time other changes were made which might have some effect on the situation. This abse of reliable data is apparent all over the field of this subject, an will therefore be impossible to say beforehand with any fair de of certainty how much, if anything, can be gained by the conver of a shop from shaft to motor drive. It will be possible, howe to indicate points which should be kept in mind, and which are controlling factors.

5 Economy is the art of obtaining the greatest output with smallest outlay. To strike a balance between these two eleme outlay and output, is the work of the industrial engineer. In a g many cases, perhaps in the majority, there are not sufficient dat enable him to do this; his work then becomes hazardous and is c level with that of the prospector. Many reputations are based a stroke of luck and many have been lost by a single wrong gu On the other hand, many hundreds of thousands, or more lik millions of dollars have been lost to shop owners by listening to lure of the enthusiastic engineer with more faith than data.

POINTS TO BE CONSIDERED

6 In considering the economical features, when converting a s from shaft to motor drive, the following points should be kept in mi

a The nature of the shop.
b The possible economies which may be effected by the ins lation of electric drive.
c The first cost of such an installation.
d The cost of its upkeep.
e The cost per unit of power.

Though these are the main points to be considered in a prelimin investigation, they are by no means the only ones. They are cially mentioned here because their contemplation will natur lead to the consideration of other points as well.

7 As the electric drive for the machine shop alone will be con ered here, it may seem that the nature of the shop might have b

left out of consideration. In the great majority of cases, however, a machine shop is of a dual nature. A foundry or blacksmith shop, or perhaps a plating shop is connected with the establishment; or warehouse and yard service may form a considerable portion of the operations. The yard service of a plant may be of an elaborate nature, while the machining operations are of a simple nature. It may be that the machine-shop operations cannot be improved enough by the change to electric drive to warrant its installation, yet the gains to be made by converting yard cranes and other similar apparatus to electrically-driven apparatus may be so great as to make it advisable to change the mode of driving of the entire plant.

8 As to the possible economies which may be effected by a change of drive, this involves so many considerations that nothing but an exhaustive study of the entire plant in all its aspects will clearly show what may be accomplished. Though at one time the only economy considered was the saving of power, it is now well recognized that this is by no means the only or the most important economy resulting from a conversion to electric drive, and that such a conversion may even be highly economical, though there be an actual loss in power consumed.

9 To illustrate: practically all of the work done in a machine shop, or which power is used, is the removal of chips. The writer has in mind a shop where an average of 9 tons of metal is daily fed through the shop, to be made up into high-grade machinery. This metal is for the greater part cast iron, with a minority of steel and a small percentage of bronze and other metals, just as in most machine shops. The total of chips removed amounts to less than 15 per cent or 2700 lb. of metal in a nine-hour day, making 300 lb. per hr., or 5 lb. per min. This shop uses an average of 225 h.p., which is 45 h.p. per min. for each pound of chips removed. Figuring that all the chips are steel, this would mean that the shop requires about 12 h.p. per cu. in. of steel removed. It should be noted that this shop is to a large extent electrically driven, and otherwise as well or better equipped than the majority of machine shops. The power costs about $40 per h.p. per year, or a total of $9000, which includes steam for heating, however.

10 Figuring that all of this amount is spent for power, and that half of it could be saved by some other mode of driving, then the total possible gain would be $4500 per year. This shop employs about five hundred men, so that the gain would be $9 per man per year. An establishment of this kind and size delivers a product of

about $2000 per man per year. If the installation of a new mode of driving could increase this output only 5 per cent, then the gain per man per year would be $40, or more than four times the gain which can be made by cutting the power consumption in two. Obviously then, the problem is to increase the amount of chips made in a given shop, and not to diminish the amount of horsepower for a given amount of chips. This phase of the subject will be treated more extensively later.

11 As to the first cost of installation, though it may be beyond doubt that a change in the mode of driving might effect economies, yet it remains to be shown that these economies will give a good return on the investment, and further, that this same investment could not be used in another direction to better advantage. What is true when a shop is to be converted from one drive to another, is also true when a new plant is to be built. Directors of industrial undertakings have frequently been criticised for apparent lack of progress, when a close analysis might have shown other more crying needs for the investment of the capital at command. Though the shop of an industrial undertaking may be the only place where its product is made, it may not be the only place where its money is made. And even should the shop be beyond doubt the best place to invest the money on hand, it remains to be shown that the proposed change of drive will bring better returns than improvements along other lines. This question will also be dealt with later.

12 The probable cost of upkeep must also be thoroughly investigated, especially as it is likely to be under-estimated unless one goes fully into details. In considering the probable economies, this cost of upkeep has to be estimated and deducted from the gross gains; but the same item appears again in the form of disturbance of operation, when it is much harder to estimate it. This must be done as well as possible, however, before reaching a final conclusion. These disturbances make themselves felt, especially the first few years after making the change.

13 It is further true that radical changes are usually made at a time when there is a heavy demand on the shop, either because it is thought that the output can be increased by the contemplated changes, or because the size of the power plant has not kept step with the growth of the rest of the plant, or because at such times of business prosperity, money can be easily obtained for such changes. Whatever the reasons, the fact has been fairly well established; and a change at such a time must be doubly hazardous, not only

because it may fail to accomplish the desired increase of output, but because it may actually prove to be a source of disturbance, and reduce the output instead of increasing it.

14 The cost per unit of power should enter into the preliminary considerations, as it will determine to a large extent the kind of current to be used, and this may have a decided effect on the final economy of the system as applied to the shop. Attention will again be directed to the foregoing items later in the paper.

SAVINGS EFFECTED BY ELECTRIC DRIVE—INCREASED OUTPUT

15 The savings effected by driving the shop electrically may be classed under two heads: increased output and less expense. Whether savings can be effected by increasing the output depends on so many and such varied items that it seems best to show them first in an elementary way, by considering a single machine under a set of assumed conditions.

16 Let us take for example a 12-ft. boring and turning mill, used in a shop devoted to the manufacture of a single line of product and having enough machines of each kind to allow each machine to be devoted to a very limited line of operations. Suppose the machine under consideration to do nothing but turn up large rings, ranging in diameter from 12 ft. to 8 ft.; and further, that a great number of rings of each size are to be turned up in each lot, so that the amount of time lost in setting the machine for the different kinds of work becomes negligible. Let it be further supposed that the machine is provided with a number of speeds in geometrical progression, with steps of 25 per cent, and that there is one speed which happens to correspond to the proper speed for the material used and for a diameter of 12 ft. This is supposing a set of conditions as good as can be expected in the ordinary commercial machine.

17 Under these conditions, the low speed must be used for all rings from 12 ft. down to 9.6 ft., and the next higher speed for all rings ranging from 9.6 ft. down to 8 ft. Supposing that the number of all rings of the same size is the same, it follows that the machine runs $\frac{6}{10}$ of the year on the lower speed, and $\frac{4}{10}$ of the year on the higher one. Allowing $\frac{1}{4}$ of the total time for chucking work, removing it, changing tools, etc., there remains $\frac{3}{4}$ of the year spent in removing chips. The machine removes chips, therefore, at the lower speed during $\frac{9}{20}$ ($\frac{6}{10}$ of $\frac{3}{4}$) of the year, and $\frac{6}{20}$ ($\frac{4}{10}$ of $\frac{3}{4}$) of the year at the higher speed. This higher speed might be called 12, and the

lower speed 9.6. A measure for the amount of chips removed, and, therefore, for the number of pieces turned up, would then be the amount of time multiplied by the linear speed of the tool. This is not exactly correct, but near enough for a mere illustration.

18 So far, however, an expression has been found only for the number of revolutions of the machine. In order to reduce this to linear speed, we must consider the fact that the higher speed is the proper speed for a diameter of 9.6 ft., and the lower speed for a diameter of 12 ft. If the machine were to run all the time at the speed corresponding to the diameter to be turned up, the total output for the year could be expressed by the time the machine is actually removing chips, which is $\frac{3}{4}$.

19 When running at the lower speed, however, the machine has the proper speed only when the diameter to be turned up is exactly 12 ft. At all other diameters, the speed is too low. The effect is the same as if the machine were running all the time at the lower speed, and all the work were of a diameter of the mean between 12 and 9.6, or 10.8. Therefore, when running on the low speed, the output runs down from $\frac{9}{12}$ to $\frac{81}{200}$. Similarly, the output of the machine, when running at the higher speed, has been reduced from $\frac{6}{12}$ to $\frac{55}{200}$, and the total from $\frac{3}{4}$ to $\frac{136}{200}$, or a reduction of nearly 10 per cent. Now if this machine were driven by a variable-speed motor, it would be possible to find a proper speed for every size of ring to be turned up, and the production might be increased from 136 to 150, or a gain of nearly 11 per cent.

20 Merely to say that there is a gain in production of 11 per cent is perhaps sufficient to prove that under certain conditions a change from belt to motor drive may be profitable, but it is in no way a measure of the amount of profit. If, for instance, the machine is capable of taking care of all the work in the shop, then the only gain is in the wages of the operator; if, on the other hand, there is more work than the machine can take care of, then the increased production of the machine may mean a corresponding increase in the production of the entire shop, improved deliveries, and the avoidance of a great deal of confusion, of which the money value may be many times greater than the mere saving in wages.

21 In the foregoing example, the advantage gained is entirely due to the fact that a variable-speed motor was attached to the machine. This is by no means, however, the only reason why the change to electric drive may increase the efficiency of a machine. The electric drive may enable one to place the machine in a more

convenient position, or bring it under a crane; or it may be the means of giving the machine more power than it could have with a belt drive; or again, it may be the means of doing away with some harmful conditions which have diminished the machine's efficiency. Among such circumstances may be mentioned the variation in length of belts due to weather conditions, or to varying loads on an upper floor, making the belts from pulleys attached to the under-side of this floor either too loose, having been adjusted at a time when the load on the upper floor was light; or too tight, owing to adjustment at a time when the load on the upper floor was heavy. Then there is the convenience of altering speed if a machine has a motor or a convenient gear drive, when the operator might forget that there is such a thing as a change of speed for varying conditions of work, if he had to shift a belt. An almost unlimited number of considerations affect the result to be obtained from the application of a motor to a machine tool; so that it is almost impossible to forecast the economy which will result from such a change, though it may be perfectly possible to say that the change will be beneficial to some extent.

22 The fact that the change from one style of drive to another is practically always accompanied by some other changes, either in addition to, or as a result of the change of drive, makes it impossible to show by data how much gain is the result of this change. Under very definite conditions, such as were supposed in the example given, it may be possible to calculate these gains beforehand, and even to verify the calculations by the actual results, but in the vast majority of cases neither calculation nor verification is possible. For this reason, this paper is confined to pointing out in which respects and under which conditions profits may be expected. Such profits will appear either in increased output or in the curtailing of expenses.

23 We will now consider more in detail the economic advantages mentioned in the foregoing paragraphs. Fig. 1 shows the main points in which an increase in output may be expected from the substitution of electric drive for shaft drive. The electric drive will show its effect on individual machines (provided they are individually motor-driven), on the handling of the work in the shop, on the light and cleanliness of the place, on the possibility of making changes in the arrangement of the shop when needed, and last, but not least, on the individual effort of the operator.

EFFECTS OF ELECTRIC DRIVE ON INDIVIDUAL MACHINES

24 *More power.* The greater output of individually motor-driven machine tools is due to a number of items, shown in the diagram. The first item, more power, is especially prominent in heavy tools. The power of cone-driven machines is limited by the belt speed, and by the width possible, considering that the belt has to be shifted. It might be said that a single-pulley drive has no such limitations;

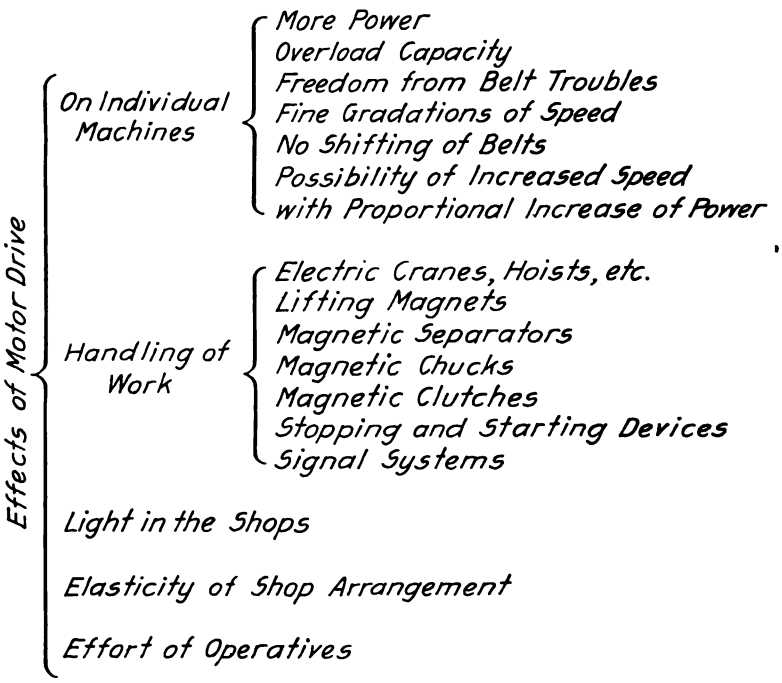


FIG. 1 DIAGRAM SHOWING THE ADVANTAGES OF ELECTRIC DRIVE

but on the other hand the single-pulley drive does not lend itself to fine gradations of speed, especially in heavy machinery. Further, such a drive would take up a great deal of space, would be very costly, and would be extremely awkward to handle, unless auxiliary mechanism were provided to do the shifting of the heavy gears, which is a further source of expense. The electric drive, on the other hand, would allow of a motor with a certain amount of variation of speed, which, combined with a few gears, would give all the variation

obtainable with the cone pulley, and by much finer gradations. This is so well recognized at the present time, that very few heavy machines are built to order with a cone drive.

25 High-speed steels made an increase of power imperative for some of the heavy machines, and for some of the lighter ones as well. In a number of cases, it was found that the frame of the machine, as well as most of its mechanism, was strong enough to stand this increase of power, but that it was practically impossible to substitute larger cone pulleys without rebuilding the entire machine; in all such cases, the electric motor has proved to be the solution of the problem.

26 *Overload capacity.* The electric motor not only makes it possible to give more power to the machine, but it gives it a reserve capacity that a belt-driven machine cannot have. For instance, a casting has to be turned up: it has a swelling where the seam of the parting is, and the amount of metal at this one point is too much for a single cut; the machine stalls. If the machine were motor-driven the overload capacity of the motor would carry the cut past this point, without harming the motor. In other words, a motor acts on a machine tool somewhat as a flywheel acts on an engine. Before electric drives were known, the power of the machine tool was almost always its weak point; after electric motors were applied to existing machines, it was the frame of the machine which had to be treated with consideration.

27 *Freedom from belt troubles.* The elimination of belt troubles is one of the strongest points in favor of the electric drive. During an investigation of a large Western railroad shop by the writer, this point was shown with exceptional clearness. Practically all machine operators "nursed" their jobs because they had to wait too long for the chief millwright, who thought he was the only man capable of putting on or correcting a belt in the proper manner. Out of consideration for the machine tools, this man would put on belts from ½ in. to 1 in. too narrow. The combination of these two pieces of foolishness reduced the output of the belt-driven machines fully 50 per cent where heavy cuts had to be taken, and reduced the output of the entire machine department at least 10 per cent. It might be said that the management should have corrected this evil, and so it did, but only after the evil had existed for a great many years. Conditions such as these are the outcome of growth, and are generally not found out until the shop becomes too small for the work to be done and the management begins to cast around for means to increase the output.

28 Belt troubles are caused by so many conditions that a shop is rarely free from them. It was observed at the shops of a machine-tool concern in the Middle West, that the output of their milling machines was increased 25 per cent by driving them by electric motors, though no further changes were made. This instance deserves attention, because while some of the machines were changed to electric drive, other similar machines were left with belt drive, and there is a clear chance for comparison. The main reason for the increased output was supposed to be the avoidance of belt trouble. These milling machines were located on the first floor. The second floor was also used for a machine shop, and was at times heavily loaded with finished and unfinished stock; this variation in loading causing a variation in the deflection of the upper floor that made it necessary to keep the belt very slack, for fear it might be too tight when the upper floor was not loaded. Weather conditions have a similar effect; especially where there are rapid changes in humidity. The effect is to lower the capacity of the machine by a large percentage.

29 *Fine gradations of speed.* Another reason for the greater economy of motor-driven machines is that finer gradations are obtainable with a motor drive. Of course, this benefit is derived only from a variable-speed motor. When attention was called to this feature earlier in the paper, nothing was taken into consideration except the fact that it would be possible with the variable-speed motor to obtain a speed in accordance with the material to be cut, and with the diameter of the work or of the cutter. However, there is more than this to be considered. A lot of castings are seldom or never of uniform hardness. This being the case, it is quite natural for the operator to set his machine for the hardest piece in the lot, and it may well happen that he strikes the hardest piece first. Where he has simple means for varying his speed, he will be governed entirely by the hardness of the piece on which he is doing work.

30 *No shifting of belts.* The fact that no belts have to be shifted is another cause of increased efficiency. The machine operator who shifts belts for pleasure has yet to be found. Besides, where the ceiling is high, it is not easily possible to shift a belt without the aid of a long stick; and this stick is generally somewhere else. The amount of time lost in hunting for the stick, and in the operation of shifting the belt, may be quite considerable in itself, especially in shops where small lots are the rule and where it does not pay to perform only one operation at a time, so that a single piece must

receive all the operations of a certain machine before it is taken out of it.

31 But worse than the loss of time in shifting belts is the fact that this shifting is generally entirely neglected, and all the various operations are carried on at the speed of the slowest. There are cases where the gain due to this feature of the motor drive may be negligible and there are other cases where this gain may be a large percentage.

32 *Increase in power with increase in speed.* Another point in favor of the motor drive, is the fact that it is possible to speed up a machine with a proportional increase in its power. This problem appears whenever a change is made from carbon to high-speed steels; and though most shops at the present time are provided with high-speed cutting tools, this is by no means true to such an extent that this point may be overlooked. There are few, if any shops where some operations are not done with carbon-steel tools, sometimes because high-speed steel has been overlooked, but more often because no benefits would be derived from it, as the machine could not be run at a higher speed without cutting down the depth of cut or feed. In some cases, this can be corrected by putting a larger pulley on the lineshaft; but in the majority of cases which have come to the attention of the writer, this could not be done without more elaborate changes.

33 Generally speaking, it is a small thing to increase the speed of a motor-driven tool without cutting down its torque. Not long ago a number of cases came to the attention of the writer, which put this matter to him in a very clear light. Some boring machines, used for boring holes out of the solid in steel bars, and using twist drills for this purpose, were supplied with high-speed drills; but it was found that the feed could not be increased, as the machine was run to the limit of its capacity. It was further found impossible to shift the belt to a larger step of the cone, thus giving more torque, as it was not practical to increase the speed of the machine without making extensive changes in the arrangement of the lineshaft. A motor drive would have solved the problem and would have increased the feed from $\frac{5}{8}$ in. to $1\frac{1}{8}$ in. per minute. Such instances are by no means rare. It is this feature of the motor drive which makes it possible, in many cases, to get the full benefit of high-speed steels with old machines.

HANDLING OF THE WORK

34 *Electric cranes.* Electric current in a shop not only makes it possible to get more production from machines individually, but admits of a number of improvements in the handling of work. The electric traveling crane has become such a common aid in the shop that it is almost difficult to realize that it is only twenty years since it was new. It is also hard to realize that it is one of the possibilities of the electric drive. The effect of the electric crane on the economy of the shop cannot well be over-estimated; though it is difficult to express in figures the amount of this economy. So much can be said, that only a few shops are over-supplied with cranes, while in a great number more cranes could be placed to good advantage. The installation of electric cranes or hoists in a shop is somewhat similar to the installation of compressed air. It is generally difficult to estimate beforehand with certainty the amount of savings to be effected, or to realize the various uses to which the apparatus will be put, but once a compressor is installed its capacity is soon exceeded; similarly, the electric crane is soon overworked.

35 The proper choice and installation of electric cranes and hoists is a separate branch of industrial engineering, though not generally considered as such. The best effects can be had only when the apparatus is taken into consideration with the placing of the tools in the shop, and the laying out of the shop buildings. Instances where the exact amount of savings effected was known even after the new apparatus had been installed for some time, are also rare, though not quite to the same extent as data about machine tools. The installation of a yard crane in a flask yard reduced the number of laborers from nine men to two and the crane tender. The installation of a small electric hoist, on a small traveler worked by hand, increased the output of a milling machine, besides doing away with the help of a laborer. It should be remarked here that the weight of the piece to be milled was too much to be lifted by hand, and that the time used for the operation proper was small. Instances of this kind are not rare and have come under the observation of almost every engineer connected with industrial establishments.

36 *Lifting magnets.* In line with electric cranes are lifting magnets, which are to be considered as an adjunct to the crane. They can often be used to good advantage for lifting plates, for loading and unloading pig-iron and scrap, for hauling small castings in quantities,

and even larger castings, provided their shape and the distribution of metal makes them adapted to this mode of handling, for lifting drop weights, and for a number of other purposes. Though no instances are at hand, it seems to the writer that a small lifting magnet could be used to good advantage for collecting chips at the various machine tools in a shop.

37 *Magnetic separators.* Magnetic separators, though more commonly used in the foundry, are used also in the machine shop for the complete separation of the chips of various metals. However, they seem to be more of a luxury than of a necessity.

38 *Magnetic chucks.* This cannot be said of magnetic chucks, which make it possible to do quickly, conveniently and accurately a great many jobs which would be very difficult, if not impossible, without this piece of apparatus. Magnetic chucks are of special merit in combination with small planers, shapers, milling machines, lathes and grinders. Their economical value may range from that of a mere aid to the operator, to the means of doing a job which could not otherwise be done at all. It is generally easy to estimate the savings to be effected, as the time for ordinary chucking methods is well known, and the time for chucking by means of the magnetic chuck is practically negligible; further, the amount of power used for the chucks does not need to be taken into consideration. They have their limitations and are not adapted to all or even to a great number of operations; but where they are applicable at all, they are of great value.

39 *Magnetic clutches.* Magnetic clutches seemed at one time destined to play a great part in shop economy. So far, however, they have been a disappointment. This seems to be partly due to inherent weaknesses of the magnetic clutch, but perhaps more to faulty construction, and especially to the fact that those who designed and developed the magnetic clutch did not quite clearly understand the requirements of the machine tools to which they were to be applied, and further, that those who had to apply the clutch to machine tools did not understand the peculiarities of a magnet. There never was the hearty coöperation that would make the magnetic clutch a success.

40 It would not be surprising to see the magnetic clutch come to the foreground once more and claim its own. There seems to be a field for this kind of apparatus in controlling mechanism of all kinds, as well as for braking the movement of a machine or a part thereof. Its peculiar value in this respect would be to give the

operator the means for controlling his machine by merely touching a button or turning a small switch. The magnetic brake is employed now, especially in cranes, indicating that there is nothing inherent in the magnetic clutch which makes it unfit for application.

41 Attention might be called here to the possibilities of the application of the magnet in its various forms to operations in the shop, and to the performance of certain functions in a machine tool. Magnets now are employed for holding small portable tools in position, and might be used for vises and other handling devices. Further attention should be called to the possibility of using the motor itself as a brake, by short circuiting the armature on a given amount of resistance.

42 *Stopping and starting devices.* In the previous paragraphs, mention was made of the possibility of applying the electric magnet for the purpose of controlling a machine. This might be called control from a distance, though, in the applications hinted at, the distance would be very small in most cases. There is no reason, however, why this distance could not be increased at will. As a matter of fact, a number of installations are in existence where electric devices (though not necessarily electro-magnets) are in use for this very purpose. They will be found especially in rolling mills, and other plants where given amounts of material have to be handled continuously. These devices enable the engineer to minimize manual labor, besides making the plant safer and the action more continuous.

43 *Electric signals.* Electric signal service in shops was well known before the electric drive was thought of, but it can be greatly improved where electric power is at hand, as lamps of different colors, placed in the shop, will transmit intelligence better and with less confusion than electric bells. The telephone would come under the head of electric signals, but it is not dependent on the use of current in the shop.

OTHER BENEFITS FROM ELECTRIC DRIVE

44 *Lighting.* One of the greatest blessings of the electric current in the shop is electric lighting. This is so generally acknowledged, and so universally employed, however, that it would be a waste of space to go further into this matter here.

45 *Elasticity of shop arrangement.* Another great benefit of the electric drive is elasticity of arrangement. Growing establishments

have had to be satisfied with arrangements of machinery which had no other point in their favor than that they were the only possible ones. It was often necessary to place departments where they should not be, simply because it was not possible to drive the machinery in them if they were placed elsewhere. The electric drive makes it possible to change the arrangement of the machinery, and the relative location and size of the different departments, according to the changing needs of the shop. This principle of changing the shop according to the work to be done, is carried to its logical limit in the system of floor plates and portable tools.

46 Besides making alterations in an existing arrangement possible, the electric drive also allows departments to be placed far enough from each other so that each may be extended separately, without interfering with the other departments. This was generally not possible with belt drive, as the distances became entirely too large. It was generally found necessary for large plants to have a multiplicity of engines. A number of the best known modern shops are witnesses to the advantage of electric drive in the matter of arranging buildings and departments. It is hardly necessary to mention that the established ideas in regard to shop arrangement had to be largely revised and that there is even now considerable uncertainty as to what is the best possible arrangement, but it is safe to say that there is little divergence of opinion as to what kind of drive will give the greatest possible elasticity, if elasticity is required or deemed advisable.

47 *Effect on operatives.* It was mentioned before that the variable-speed motor, applied to a machine tool, induces the operator to experiment with the best possible speeds. There is, however, another way in which the electric drive affects the efforts of the men. It is nowadays well recognized that favorable conditions in regard to light, heat, sanitary conditions, etc., have their immediate effect on the output of the shop. These conditions cannot be ideal with a confusion of belts obstructing light and gathering and distributing dirt. Though in most electrically-driven shops belts are not entirely absent, they are so few that their evil effects are reduced to a minimum.

RELATION OF FIRST COST TO DECREASED EXPENSES

48 Whether savings are effected by lessening expenses depends on the nature of the old installation and that of the new one.

49 The writer was at one time connected with a large manufacturing plant, spread over a large tract of ground, which in its general layout and operations is fairly representative of a great number of existing manufacturing plants. It was at that time steam-driven, as the motor had not been sufficiently developed for a complete electrical drive to be considered. However, the management being progressive, partial conversion to electric drive was considered even at that time. The plant included two multiple-story buildings used as machine and erecting shops, a forging shop, a building used for some machine operations, for dropping malleable castings and for a warehouse, a wood-working shop and warehouse, another warehouse, and a malleable and a grey iron casting foundry. There were in all five engines driving these different shops, with the necessary transmissions from one building to another. In a few cases, quite elaborate systems of shafting were installed to drive a single piece of machinery; such, for instance, as the elevator in the warehouse. The engines ranged from 150 to 500 h.p. It was not possible at that time to determine accurately the aggregate of power consumed in that plant, but it was estimated that a single 1500-h.p. engine would carry the entire load. In the light of later developments, this amount now seems excessive, as a number of shops have since found that the amount of loss by friction in the transmission is greater than was estimated at that time, namely 30 per cent. The single engine could have been run condensing, as plenty of water was at hand. The several smaller engines did not pay, of course.

50 The following items would have decreased expenses, if this plant had been driven electrically:

a Lower first cost of engines.
b Lower first cost of boilers.
c Lower cost of piping.
d Lower cost of power houses.
e Lower cost of stacks.
f The omission of all transmission machinery.
g Greater economy of the engine in its steam consumption.
h Economy in oil and waste.
i Economy in repairs.
j Reduction in the number of engineers required.
k Reduction in the number of firemen required.
l Saving in the handling of coal and ashes.

m A probable more even load during the day, as the greater number of machines on a single engine has a tendency to equalize the load.

51 A number of these points are of value when a power plant is newly built, but are of no value where an established power plant is to be changed. To offset the above items the following must be considered:

a Greater first cost due to the generators.
b Greater first cost due to the wiring.
c Greater first cost due to the motors.

52 Besides, there are a great number of other factors to be considered. In this plant there were no duplicate engines, so that it would not be fair to figure in the first cost of the electrical installation of a reserve unit; though, of course, good present-day engineering would consider this an absolute necessity. It is true that where there are a number of engines, the breaking down of a single engine does not throw the entire plant out of action; but it is also true that in the plant under consideration the stoppage of a single department would soon have closed the entire plant. Considerations of this kind cannot be generalized, but must be taken up in detail in every specific case.

53 Another point to be kept in mind is, that copper wire largely takes the place of transmission machinery, and that such wire is an asset with practically no depreciation except that due to fluctuation in price (and this may be up as well as downward). On the contrary, transmission machinery should be considered as an expense, as in most cases it has no value except as scrap iron when no longer in use.

COST OF UPKEEP

54 Still another point, and one which should have most careful consideration, is the value of the time of the plant, and the relative chances of a breakdown. In some plants the process is continuous: that is, the product goes from one machine to another without interruption, and the breakdown of a single machine would cause the stoppage of the entire plant. In such cases the breakdown should be charged with the amount of the productive capacity of the entire plant during all of the time lost. In other plants the various machines balance each other only roughly and often there is a small

surplus of almost all kinds of machines in use, while some of the machinery is used only part of the time. Where these conditions prevail, the loss due to a breakdown of a single machine may be simply the cost of repairing the apparatus. In a majority of cases, neither of these two extremes is the true condition, and the engineer considering the kind of drive to be used must make some estimate of the loss due to a breakdown in any part of the installation. It should be kept in mind that the correctness of his estimate can never be established by positive proof; for, no matter which course he takes, it is impossible to say positively what would have been the result if he had pursued the other.

55 Though all of the points mentioned above affect the ultimate economy of the power installation, their relative importance changes with local conditions. For example, while the saving in the coal bill may be of the greatest importance where coal is high-priced and where the expenses for power are a large portion of the total expenses, this saving may be a vanishing quantity where coal is cheap, and where the expenses for power form but a small fraction of the total expenses of the plant.

56 While in the example cited there was a decided saving in the number of engineers required there may still have been a loss on this score, due to the fact that in some small plants a high-grade engineer must be employed for an electrical installation, whereas a combination engineer and fireman would be good enough for the engine-driven proposition. And so on all along the line: what is a saving in one case may be a loss in another.

COST OF UNIT POWER

57 In practically all cases which have come to the notice of the writer, the cost of power per unit has gone down after conversion to electric drive, but in no case was it possible to point out in what way the saving was effected, as in addition to the substitution of electric drive for shaft transmission there were always other changes which might affect the cost of the power. Such changes were, more efficient engines, better boilers, new auxiliary devices, etc. Also in all these cases, the amount of power required after the conversion was greater than before: this was not proof that the new installation was less effective than the old one, however, the probable cause in all these cases being that the output of the shop increased much more than the amount of power saved would have taken care of. It

is almost to be regretted that high-speed steels made their entrance into the shop almost simultaneously with the electric drive. Though both are good, they have obscured each other to such an extent that it is almost impossible to trace the effects of each item separately.

CHOICE OF THE ELECTRIC SYSTEM

58 If, after considering all these points in a general way, the engineer comes to the conclusion that the electric drive will decrease expenses, then the next step will be to select the nature of the drive. The diagram in Fig. 2 shows the main points to be considered.

59 Whether a central generating station or a multiplicity of smaller plants is preferable, depends again on local conditions. Certain conditions might make a number of generating plants preferable, as, for example, in a plant which consists mainly of a machine shop requiring considerable power, with a smaller wood-working shop located at a considerable distance from the rest of the plant. In this case, the outlay for copper to supply the wood-working shop with power would be considerable; whereas by placing an individual generating plant near the wood-working shop, the shavings might be used instead of coal.

60 Another case would be where a portion of the shop requires a great amount of power, but only for a short time each day, or perhaps at long intervals, thus necessitating a large outlay in generating machinery and copper. By separating this part of the plant, the outlay for copper is avoided and a cheaper class of generating machinery may be used.

61 The writer has in mind a plant devoted to the making of electric generators and motors. By far the greater part of its output is in

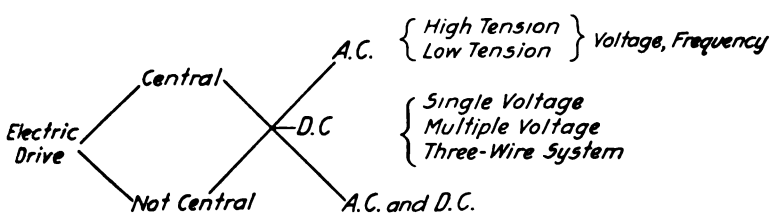


FIG. 2 DIAGRAM SHOWING THE DIVISIONS OF ELECTRIC DRIVE

smaller units, but a certain small percentage is in larger generating units. The power required for testing these large generators exceeds

all the power required for the operation of the entire plant. This plant gets its current from a central station near by, but the amount of copper required for the large testing currents would be more than the cost of installation of a cheap gas engine and generator. Here again the engineer must consider conditions as he finds them and must not be governed by general principles only.

ALTERNATING OR DIRECT CURRENT

62 The question whether alternating or direct current should be used is especially difficult of solution, and there is a wide difference of opinion among engineers as to which is best. It may be that too many engineers look at this proposition only from a power standpoint, without giving due attention to the output of the plant. Commercial reasons also have figured largely in the past, the representatives of companies manufacturing both kinds of apparatus naturally advocating the alternating variety, as by so doing they eliminated some competition. Now that more electrical companies manufacture alternating apparatus, this phase of the matter has almost entirely disappeared.

63 *Alternating current.* It may be said that, all other conditions being the same, alternating current offers an advantage when the distances over which the current must be transmitted are considerable. The fact that current can be generated at high voltage diminishes the amount of copper needed for transmission, but here again the problem is not simple. Attention must be paid to the expenses incurred in step-up and step-down transformers and auxiliary apparatus; and also to the fact that money invested in copper conductors is lost only in part, while money invested in auxiliary apparatus is lost almost entirely in case of a change. There are a number of cases where the installation of alternating current would be the only practical solution, on account of the long distances and the heavy currents to be carried.

64 The advantages of alternating current, as well as its disadvantages, are well understood, and it is unnecessary to call attention to these points. It may be well, however, to point out instances where it is easy to make a choice. Given a plant covering a large area and using large amounts of current, of which only a small portion is used for variable-speed machinery, and of sufficient size to permit of the use of a separate unit for lighting current, alternating current would be the logical solution. On the other hand, given a compact plant, using a large portion of the power for variable-speed machinery,

direct-driven by motors, and of which the lighting load is small in the daytime, it would be natural to select direct current. As a rule, however, conditions are not so simple, and it is generally very difficult to prophesy which system will give the best results. Of late the problem has been complicated by the fact that a great many machine tools may be had with single-pulley drive, to which an alternating-current or a direct-current motor is equally applicable.

65 The points in favor of the alternating-current motor are then:

a High breakdown point; that is, the motor goes on with no material change in speed under very heavy overload.

b Freedom from commutator trouble. This is especially valuable where fine chips are made, or where compressed air is used in connection with the machine. It is not such a weighty point as it used to be, as the better makes of direct-current motors are now equally free from this kind of trouble.

c Most cities are now lighted by alternating current, so that city current can be used in smaller plants, provided the machine tools are arranged for this kind of motor.

66 *Direct current.* The points in favor of the direct-current motor are:

a Wider air-gap, allowing a greater amount of wear in the bearings before the motor has to be repaired.

b The possibility of power and lighting-loads on the same circuits without the poor regulation due to inductive load.

c The possibility of using variable-speed motors. This is, perhaps, the greatest argument in favor of the direct-current motor. Though it is possible to run a great many machine tools by a motor, yet one of the greatest advantages of such a drive is not available unless the motor is of the variable-speed variety.

67 *Alternating voltage.* When a decision has been reached as to the nature of the current to be employed, the next step will be to decide as to the voltage. A high voltage is likely to be in favor if distance was a controlling factor in the decision to use alternating current: for it is this possibility of using high voltage, which makes alternating current desirable under those conditions. Where the distances are relatively small, it becomes simply a matter of computation whether low copper cost plus the expenses for transformers, etc.,

will give greater or less economy than high copper cost without auxiliary apparatus. In a great number of cases, current is bought from some power company, and in such cases there is no choice. In any case, however, it remains to be decided to what voltage the current shall be transformed. Few engineers nowadays adopt the 440-volt current, on account of the greater danger, and for the same reason 500-volt direct current is very little used. It should be kept in mind that alternating current is more dangerous than direct current of the same voltage.

68 *Frequency and phase.* Frequency depends on the use to be made of the alternating current. In late years a compromise has been reached, which fills practically all wants of the shop by one single frequency, namely 60 cycles.

69 Though there is still some difference of opinion, the question of the number of phases is now fairly well settled in favor of the three-phase current. It would be difficult, however, to point out the advantage of this system over the two-phase system, or vice versa, as far as use in shops is concerned.

70 *Direct voltage.* The choice of voltage is easier when direct current is used. There was a time when the multiple voltage seemed to take a strong hold on engineers for use in machine shops, and the writer must confess that he had strong faith in the ultimate success of this system. However, the development of the variable-speed motor has made the system somewhat superfluous and it has not been installed in any new shops of late. It might be said that, for all practical purposes, the system is dead.

71 There is, however, a kind of multiple-voltage system in use which deserves even at the present day the serious consideration of the engineer. This is the three-wire system, which allows of the use of 110 and 220 volts in the same shop. The 110-volt system alone would require a large amount of copper for power purposes, while the 220-volt installation leads to some difficulties in regard to lighting. However, there are many installations where the 220-volt system is used throughout, both for power and lighting, while the number of shops where a 110-volt system is used for both purposes is very small.

72 There are a few shops using 500 volts, but the number is very small as compared with the other voltages; and it is generally possible to trace the reason for such an installation to the fact that the 500-volt current is available because used for some other purposes, as, for instance, in the case of a repair shop for a street railway system. This system is not to be recommended for a shop (though it is economical

in the use of copper), for the reason that it is dangerous and where there are a large number of circuits and much metal in buildings and machinery great care must be taken to avoid grounds.

73 *Combined alternating-current direct-current systems.* There is finally the combination of alternating and direct current to be considered. This combination has its advantages, especially where it is possible to purchase current from some large power company, which as a rule delivers its product as alternating current. Transformers reduce the voltage to the proper point at the entrance to the shop, and the low-voltage alternating current can be used for all purposes except for driving variable-speed motors, and perhaps some auxiliary apparatus such as magnetic clutches, lifting magnets, etc. As the cost of installation is generally low in such a case, and the price per unit of power usually less than it could be made for, such an arrangement is so inviting that a number of objectionable features may be overlooked. The most serious objection, perhaps, to this method of driving a shop, is that the shop has absolutely no control over the supply of current, and there is nothing to be done in the case of a breakdown but sit down and wait. This is especially serious, as power delivered in this manner is generally transmitted over a long distance which increases the chance of a break in the wires, especially in bad weather.

METHODS OF APPLYING MOTORS TO MACHINE TOOLS

74 The mode of application of a motor to a machine tool, the selection of the motor, and the lines along which economical results may be expected, are fairly well defined at the present time. The following tabulation shows the present state of the art.

75 *Bench lathes:* To be driven from a countershaft, attached to the wall or bench and driven in its turn by a motor. Any kind of motor, except a series-wound or heavily compounded motor, will do. The object of the motor drive is to get the machine in the best possible location without regard to the location of the lineshafting. A number of these machines may be driven by a common lineshaft, driven by a motor.

76 *Speed lathes:* To be driven from a countershaft, located under the lathe, or by a direct-connected motor. In the latter case, a variable-speed motor is to be preferred, if direct current is available. Motor drive is recommended when the machine is used in the assembling department, as the machine may then be placed where it is most needed, and the assembling department being generally of greater height than

other departments crane service would interfere with countershafts. There will be no material gain, if the machine is to be used for ordinary shop operations.

77 *Engine lathes:* Various modes of motor-driving are in use. Some makers furnish motor-driven engine lathes as standard apparatus. Some have a headstock with a limited number of speeds and depend on a variable-speed motor to fill out the speeds of the lathe. Others apply a constant-speed motor, or one with a limited amount of variation, to an all-geared headstock. In general the use of this class of machines in the shop would naturally lead to group drive. The advantages of the individual motor drive lie in the possibility of completing a job in one setting. There is no material advantage, if the machines are used for regular manufacturing operations, except where the location demands the motor drive.

78 *Heavy engine lathes, forge lathes, etc.:* To be driven by a direct-connected motor. The motor should be direct-current, as these machines are too heavy to permit a convenient all-gear drive. If no direct current is available and there is only one machine of its class in the shop, and this is used for an occasional job only, an alternating-current motor could be used, leaving a wide gap in the speeds. If these machines are used for manufacturing purposes, however, it will pay to install a small synchronous connector. The speed range in the motor does not need to exceed two to one, though a wider range is better if obtainable without complications or large expenses. The position of the motor should be low, as the vibrations in the motor-support have a decided influence on the capacity of the machine, as well as on the repair bill. The output of this class of machine may easily be increased from 20 per cent to 25 per cent by motor drive.

79 Further advantages of the motor drive are, the possibility of placing the machine in the line of the routing of heavy work, and of placing it immediately under the traveling crane. This latter object may be reached with a belt-driven machine by placing the headstock under the gallery, if the construction of the shop lends itself to this arrangement, but the same convenience as that of the motor drive cannot be obtained.

80 *Axle lathes, wheel lathes and driving wheel lathes:* It is of the greatest importance that this class of machinery should have the highest possible efficiency, and the most convenient location. These machines are mostly used in railroad repair shops, where time saved does not mean merely the saving of some wages, but each day gained means an added day in the earning capacity of the engine. It is

therefore important that these machines be motor-driven whenever installed in a railroad repair shop, though this does not mean that they should not be so driven if used for manufacturing. Direct current should be used. The economy of the motor drive should not be figured in increased output, but in reduction in time required to repair an engine.

81 *Chucking lathes:* Generally speaking, there is little reason why a chucking lathe should be motor-driven. Most chucking lathes are provided with the necessary mechanism to shift speeds quickly. A few types handling large work may be motor-driven to advantage, though practically the only advantage lies in the fact that small graduations in speed can be thus obtained. Such machines therefore require a variable-speed motor.

82 *Automatic screw machines:* Small machines of this class are generally group-driven. Large machines may be motor-driven to good advantage. The larger sizes have generally one or two speeds for one piece of work, though these speeds may be varied when the machine is reset for a new piece of work. The speed given to the machine must naturally be proportional to the largest diameter to be turned, or in other words, to the size of stock used. This will reduce the speed for some of the operations, such as drilling and reaming, far below the economical speed. The amount of time saved by the application of the variable-speed motor may be considerable. Where the construction of the machine permits, two motors, one for feed and one for speed, would give still better results. In all cases variable-speed motors should be used.

83 *Sensitive drills:* The only reason why a sensitive drill should be individually motor-driven is, that it is often used in the assembling department, where height of ceiling and crane service would make a belt drive awkward or impossible. Most sensitive drills have in themselves all the speeds required for their work, so that any type of motor will be adaptable. The motor may either be directly applied to the machine or drive a countershaft on a stand, or it may be placed on the floor by the side of the machine in case the machine carries its own set of cones or other variable-speed device.

84 *Drill presses:* Generally speaking, the upright drill is used for manufacturing operations and does not require frequent changes of speed. There are, however, many exceptions, for instance, where upright drills are used to perform all the operations on a piece by means of a jig. In this case frequent changes of tools, and therefore of speeds, are required, and an individual motor drive, whether direct-connected

to the machine or operating on the countershaft, is of the greatest benefit. No great benefit can be derived from a constant-speed motor with this type of machine. Radial drills may be considered the same as upright drills. There is an additional reason why radial drills should be motor-driven—they are often used in the neighborhood of the assembling floor.

85 *Boring machines:* Where boring machines are specialized, performing only one operation, there is no good reason why the motor drive should be preferred to belt drives. Where, however, the machine is used for a multiplicity of operations, such as drilling, boring, reaming and facing, a motor drive is beneficial if a variable-speed motor is used. The range of speed of the motor should be as wide as possible, that no gears may have to be shifted for the entire set of operations on a single hole. Especially where a boring machine is used for facing, this variable speed will be found highly economical.

86 *Grinders:* Grinders in general require so many various movements driven from countershafts that it is hardly possible to apply a single motor directly to the machine. The best that can be done is to attach the countershaft to the machine, and drive the former from a motor standing on the floor or on a bracket attached to the machine. In isolated cases it would be well to have one or more motors, each controlling a single operation, attached directly to the machine.

87 *Planers:* Planers in general are not benefited by the application of a motor, as the motor only complicates the difficulties of a planer drive. However, large planers which must be placed under a crane give better results when motor-driven on account of the facility of handling the work. Another possible advantage when using a variable-speed motor and controlling the speed of the motor at the end of the stroke, is that much higher return speeds can be obtained in connection with any desired cutting speed.

88 *Shapers, slotters etc.:* What is true of planers is also true of these classes of machines. Local conditions may make it advisable to drive them individually by motor, but generally speaking, there is no great benefit from this drive.

89 *Milling machines:* The larger sizes of knee-and-column type machines, if motor-driven, will give the best results if the motor is of the variable-speed type, especially where these machines are used for gang work. This is due to the fact that the speed of the mills is dependent on the largest cutter in the gang, while the feed is dependent on the smallest cutter, not counting the limitations due to the nature of the work. It is therefore important that the speed should be

as close to the permissible limit as possible. When applied to this type of milling machine the motor should be as low down as possible, as vibrations in the machine have a marked effect on the quality of the finish.

90 *Planer-type milling machines:* In practically all cases machines of this type should be motor-driven in order that they may be located under a crane. It is not so very material, however, whether the motor is of the constant-speed or the variable-speed type.

91 *Punches, bending rolls, shears, etc.:* This class of machinery, used largely for boiler, bridge, structural iron and ship-building work, is generally placed in high shops and under cranes, and in locations and directions most convenient for the routing of the work. The shops in which they are placed are generally large and contain a relatively small amount of machinery, so that the amount of transmission gearing required is large in proportion to the amount of machinery. It is for this reason advisable in almost all cases to drive this class of machinery by an electric motor, which, of course, does not need to be of the variable-speed type.

92 It was not the intention to go into detail on the application of the motor to the machine tool, and the above should be considered as merely an enumeration of some of the important points for the most constantly used machines. It is in no way a treatise on motor drive applied to machine tools.

No. 1276*b*

ECONOMICAL FEATURES OF ELECTRIC MOTOR APPLICATIONS

By Charles Robbins,[1] East Pittsburg, Pa.
Non-Member

93 The principal object of this paper is to show, by figures and curves, based upon actual tests and investigations of existing installations, how a problem in motor drive can be handled in order to show its maximum economy. It will endeavor to show that the hourly cost of operation is dependent upon the characteristics of the various types of machine tools, from the standpoint of power and time required. The load and time factor of the tool will be taken into account and the influence of this factor on the cost of production. Data are also given upon the electric-motor equipment of machine tools, with suggestions for its standardization.

94 There are certain types of tools in which the operations to be performed require constant speed, for which service the constant-speed type of motor should be used. Other types of tools call for a cycle of duties in which the range of speed may vary almost from minimum to maximum conditions. In these cases the adjustable-speed type of motor should be used for the greatest economy. There are, therefore, in a single shop two distinct service conditions calling for different types of motors, different methods of applying the motors to the tools, and different methods of control.

95 Where direct current is available, these conditions can be met by the direct-current motor, i.e., both a constant-speed and an adjustable-speed motor is available for machine-tool work. On the other hand, the alternating-current motor is essentially a constant-speed machine. At the present time no commercial method has been found for varying the speed of an alternating-current motor in such a way that it can be

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successfully used for machine-tool service. Thus it is apparent that the machine-tool designer must take into account not only the application of the motor to the tool, but also the class of current supply available in the manufacturing establishment in which the tool is to be used.

96 An alternative method of driving is by the use of a system of gears, commonly called a gear box, driven by a single belt considerably larger than that ordinarily employed on cone pulleys. This large belt will to a considerable extent furnish the power required, the necessary changes in speed being obtained by changing the gears. Obviously, however, a gear box arrangement cannot be as convenient of manipulation as a motor controller, which can be mounted in a position easily reached by the operator. In addition to this difference between the two methods of changing speeds, the motor drive offers finer gradations of speed; that is, if the same results were obtained in a gear box, the multiplicity of gears would be considerable and the up-keep a matter to cause serious consideration.

STANDARDIZATION OF TOOL EQUIPMENTS

97 One of the great drawbacks to a harmonious design of motor and tool has been the lack of a proper understanding of the joint problems of the motor and tool builder, this condition showing the necessity of some standard in respect to speeds or speed ratios, method of control, and certain dimensions of the motor or its adaptation to the tool. There is also a lack of standardization of the method of supplying power in industrial plants. For instance, there are so-called different systems, as direct current of 110, 220 and 500 volts, and alternating current of 220, 440 and 550 volts and two or three phases; also either 25 or 60 cycles may be called for.

98 In view of the above conditions, which are in a measure arbitrary, the future development of the art will be materially benefited if some standardization can be adopted by the tool builder and the motor builder, whereby they may be able to recommend certain standard power equipments for metal-working establishments.

STANDARDIZATION TO ACCORD WITH CENTRAL STATION SERVICE

99 Central station power companies now realize the great advantage of a day load and are quoting low power rates to manufacturing establishments. It seems probable that in the future much of the power for small, and to some extent for large, manufacturing estab-

lishments will be furnished by central power companies, either those which are formed for the purpose of furnishing power only, or those which are regularly organized as public utility companies, furnishing both power and light. To this latter type of existing central power stations the day load supported by power service to manufacturing establishments is particularly attractive.

100 As most communities contain both manufacturing plants and central station companies, we look forward to an immense development of central power service, to be used by large manufacturers as well as by the smaller ones. For this reason we suggest that the class of service, i. e., the characteristics of the current supply, should be taken into account when making standards for the operation of metal-working tools.

101 The steam railroad companies as a class have been to a considerable extent the largest single purchasers of machine tools, and it is well to consider the power requirements of such classes of purchasers when deciding upon a standard of motor equipments for tools.

102 For some years it has been the almost universal practice of steam railroad companies to install alternating-current generator equipments in their power stations; these are principally of the turbine type, largely for the reason that their requirements are to a considerable extent similar to those of the central stations of power companies. They are called upon to distribute current for lighting their train sheds, stations and yards, and power for operating turn-tables, transfer tables, etc., and for the operation of their repair shops, which usually consist of machine and wood-working divisions. Because of the simplicity and the great desirability of alternating-current motors, the railroad companies have adopted them almost exclusively for constant-speed service, as exemplified in the machinery of their wood shops, and for miscellaneous power purposes, such as pumping, operation of fans, and driving incidental sections of lineshafting for supplying power to the smallest types of tools, on which it would be inadvisable to employ individual motors, and to tools requiring constant-speed motors.

103 For tools whose operation calls for adjustable speed, the standard practice is to employ direct-current adjustable-speed motors, using a controller located conveniently to the operator in such a way that the variation from minimum to maximum speed can be made with great facility, therefore affording a ready means of obtaining the maximum output for which the tool is designed.

104 It will be evident from this practice that two kinds of current are employed—alternating current for the primary and direct current

for all secondary operations. To transform from alternating current to direct current, either a rotary converter or a motor-generator set is employed, the specific selection of one or the other depending somewhat upon local conditions and the class of supervision available for the operation of the outfit.

105 The same scheme of operation can be very advantageously employed when using central station service for the operation of machine shops or metal-working establishments in which machine tools are employed. Such a standardization of tool equipments by the tool builders and the motor manufacturers would tend to place the operation of metal-working tools on a more economic basis, in that it would enable better tool equipments to be designed with a definite certainty that the motor requirements could be forecasted. As it is now, a very considerable risk is involved in designing tools in advance of orders. Few companies manufacture motor-driven tools in large quantities and the public is thus called upon to pay a higher price because of a lack of standardization.

106 On account of the fixed conditions of central station service, it is almost universal for the service to be 60-cycle, 3-phase, and as the transmission line is of relatively high voltage, transformers will be necessary at each industrial plant, and the voltage of the motor installation can thus be suited to the requirements. In metal-working establishments, where the motors can be located on the tools, or to some extent in close proximity to the metal structure, it is desirable to use a relatively low potential, say 220 or 440 volts. Thus in a measure there has been established automatically a standard for alternating-current service, consisting of 60-cycle, 3-phase, 220-440-volt, this standard being that used by most of the largest single purchasers of metal-working tools, i. e., the steam railroad companies.

107 By the adoption of standards which conform with the central station supply service, it is evident that even in the case of very large manufacturers who have their own isolated power plants, use can be made of a so-called break-down connection with the central station power company, as an extra precaution to insure continuity of service. This break-down connection can be made available only when the service supply is uniform with that employed by the isolated plant. Connection to a central power company would prove a very great advantage to a manufacturer for overtime work, when but little power is usually required, or under conditions when but a small percentage of tools are in operation, as it would permit closing down the isolated plant, and the operation of the limited service from the outside power system.

108 This standardization of tool equipments would also enable existing manufacturing plants not equipped throughout for electric driving, but requiring the service of machine tools, to make trial installations of motor-driven tools or of a rapid-production tool, in which much of the advantage to be gained is due to the motor drive.

ANALYSIS OF OPERATING CONDITIONS

109 It is only recently that data have been available to show beyond doubt the intermittent operation of the average machine tool. When a machine shop is driven by a belt from engine to lineshaft, and from lineshaft to machine tool, it is difficult to determine with any degree of exactness the length of time any particular tool is in operation, or the average time of operation during the working day.

110 With the installation of motors on lineshafts, it became evident that the total horsepower capacity of motors was much in excess of the power generated in the power station. This ratio is sometimes three to one, at other times possibly four to one.

111 As individually driven tools are adopted it is noticeable that the total horsepower capacity of all the motors connected to the service grows very rapidly, and that the ratio of the connected capacity to the power supplied is often as high as five or six to one, indicating that the time-load factor of the average machine tool is relatively low.

112 This apparent difference between the connected capacity of motors and the demand on the power station has led to a careful analysis on the part of the motor builders to determine exactly the length of time tools can be expected to be in operation.

113 An analysis which took into account the time of loading, cutting, unloading, and other delays occasioned by miscellaneous causes, showed conclusively that it was not necessary to use a continuously rated motor; in fact, an intermittent rating on the motor for a period not exceeding two hours' continuous service answers for almost all kinds of machine tool applications. This knowledge enabled the motor manufacturer to build a more economical motor, one of smaller size, and consequently reduce the expense of applying motors to machine tools. The present-day tool equipment ought not, therefore, to be much more expensive, if any, than that of the belt-driven tool, when the cost of belting, shafting and power house equipment is considered.

114 When machine tools are equipped with individual motors, a graphic recording meter may be connected in the motor circuit, making it possible to have a complete log of the operation of the particular

tool during its time of service. The chart furnished by the graphic meter will show the time of loading and unloading the tool, the time of cutting, all delays due to stoppage for one cause or another and the amount of power to operate the tool, which is a direct function of the work done.

115 Fig. 3 shows a graphic recording meter by which interesting tests have been made in studying machine tool operations. The instrument is unlike an indicating meter, in that instead of a needle

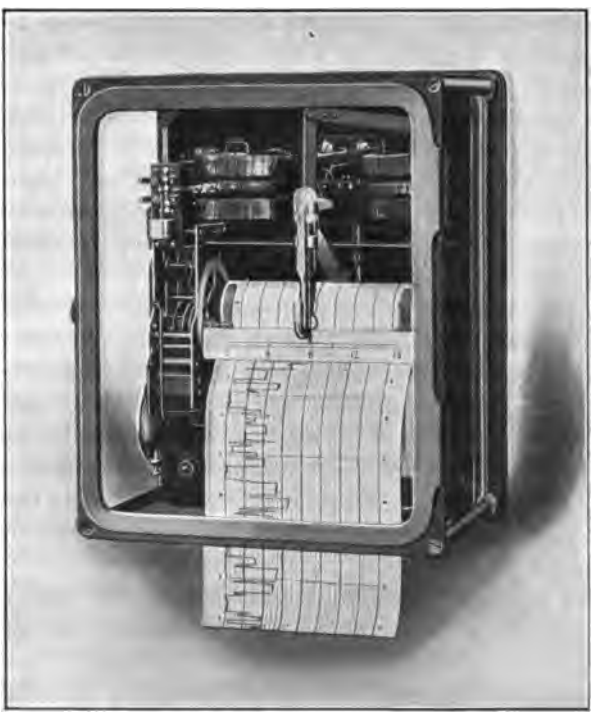


FIG. 3 GRAPHIC RECORDING METER

passing over an indicating scale, the meter is provided with a pen moving horizontally, thus making a line on a properly graduated roll of paper. The paper is moved by clockwork, vertically, and at right angles to the pen, so that a permanent record of the magnitude and time of all operating changes is obtained.

116 A time study of each tool can be made from these charts, and knowing the theoretical time for the job an analysis can be made of the

curve, furnishing information that will enable the foreman to increase the productive capacity by the elimination of delays. He will also know whether or not the tool has been working at its maximum capacity and whether the tools have been kept up to standard conditions, and in general can apply the necessary remedies.

The Economics of Motor Drive as Determined by the Actual Performance of the Tools

117 The economy of the individual motor drive, due to the fact that practically the exact cutting speed can be obtained for any operation, has been pointed out. This economy is not so important, however, as that of keeping a tool in continuous operation through longer periods of time, by reducing the time required for handling and other avoidable delays, as previously mentioned.

118 The accepted method of capitalizing motor drives seems in general to be on the basis of the incidental savings in the workman's time. In our opinion this is not the whole story by any means. When determining the monetary advantage of motor drive, the value of time saving should be considered on the basis of its effect on the total cost, which includes the workman's labor and the investment cost per hour of the tool.

119 In addition to workmen's wages, every shop has the following expenses:

a Interest and depreciation on cost of buildings and accessories.

b Repairs and renewals to existing equipment.

c General operating expenses, including losses due to defective workmanship, design and material.

d Salaries of supervisors, engineering staff and clerks.

120 These overhead charges must be included in the cost of any manufactured article. A method frequently employed is to determine from time to time the percentage which the total overhead charge bears to the cost of total actual or productive labor. This percentage in large shops reaches from 100 to 200 per cent, or even more. The total labor charge is then obtained by multiplying the actual labor cost by one plus the per cent to be added for the overhead charge.

121 This is an easy way to take care of the overhead charge; but the method is inaccurate and does not show the relative importance of different types and sizes of machines. This fact is especially important where a great variety of materials is manufactured, in shops using a

large number of different types and sizes of tools. Under such conditions, the percentage obviously varies within wide limits for different kinds of work.

122 A satisfactory method of distribution is to set off against each tool its proportion of the total overhead charges. The portion chargeable to each tool depends entirely on local conditions; and thorough familiarity with these conditions is needed in order to apportion these charges equitably. In this way, the relative importance of each machine is recognized.

123 In a shop where only one type of article is manufactured, and the castings are passed from one machine directly to the next, a simple and logical way is to divide the total overhead charge among the tools, in proportion to the floor space charged to each tool. In the majority of shops, however, the above simple condition does not exist; several sizes and kinds of articles are usually turned out, and various sizes and types of tools, differing greatly in their operating characteristics, are employed. In such cases, not only must the floor space be considered, but also the time each tool is actually in operation, the nature of the work and the amount of supervision and engineering attention needed.

124 Large shops handling different classes of materials are in most cases divided into various departments or sections, and each section may be considered as a separate smaller factory. The overhead charges against each department may thus be apportioned among its tools in proportion to the floor space occupied, making proper allowance for special local conditions, or special supervision or engineering attention. Here again is required thorough familiarity with both the engineering and the shop features of the materials manufactured.

125 In our experience we have found the overhead charges to be approximately as follows:

Variable charges	from 50 to 55%
Salaries	from 25 to 30%
Interest on cost of machine tools	from 5 to 10%
Depreciation on cost of machine tools	from 5 to 10%
Fixed charges	3%
Power	from 1 to 2%

The detail method of arriving at these general figures is found in Appendix 4.

DEFINITIONS OF TERMS

126 In discussing the economics of motor drive there will be a number of terms used which are here given with our interpretation of their meaning.

Applied to the operation:

Time factor = ratio of actual cutting time to total time required to complete a machining operation

$$= \frac{\text{Actual cutting time}}{\text{Total time to complete operation}}$$

Applied to a machine tool:

$$\left.\begin{matrix}\text{Time factor} \\ \text{in per cent}\end{matrix}\right\} = \frac{\text{Total daily actual cutting time in hours}}{\text{Total number of working hours}} \times 100$$

Average running load = average input to motor while operating, usually expressed in kilowatts, but may be expressed in per cent of full load input.

For rough calculations in this paper the input of a motor in kilowatts is assumed to be the same as the output in horsepower; that is, the motor efficiency in all cases is assumed to be about 75 per cent. This low percentage will take care of the fact that motors operate at light loads a considerable part of the time.

Maximum load = maximum input to motor, expressed in same terms as the average running load.

Average load = *average daily load* = average input to motor during the total working hours; usually expressed in kilowatts. This load multiplied by the total number of working hours gives the total kilowatt hours consumed per day, and is the basis of payment for energy. The average load multiplied by the number of hours per day and by the price per kilowatt-hour gives the cost of energy per day. The average load also equals the average running load multiplied by the time factor.

Load factor = the ratio in per cent of the average daily load to full load rating of the motor, or

$$= \frac{\text{Average daily load}}{\text{Full load rating of motor}}$$

CONDITIONS ENTERING INTO THE OPERATION OF A MACHINE TOOL

127 In order to obtain a maximum output from a machine tool, a careful analysis must be made of all the conditions entering into the operation of the tool. One method of doing this in the case of a motor-driven tool is to take power readings at frequent intervals and lay

these out on a chart basis. Another and a much more convenient method is the employment of a suitable meter, as already described, designed to make a graphic curve, showing the exact condition occurring in the service when such a meter is applied to any motor-driven tool.

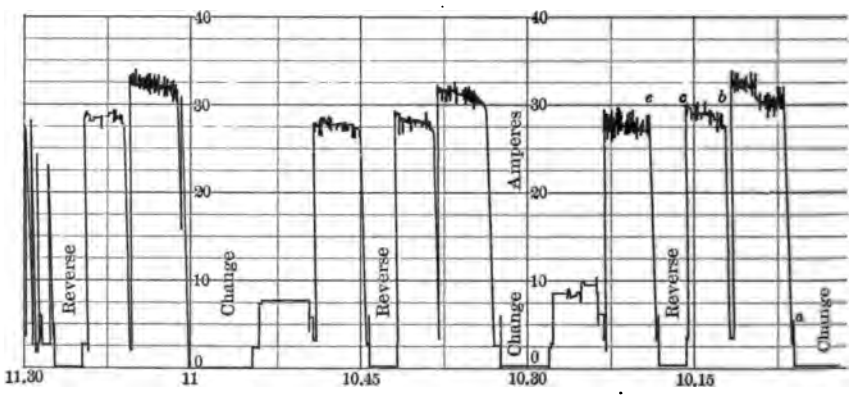


FIG. 4 METER RECORD WHEN TURNING SHAFT SHOWN IN FIG. 5

128 Fig. 4 shows a record obtained while shafts of the dimensions shown in Fig. 5 were turned from machinery steel. Both Fig. 4 and Fig. 5 are lettered for reference. The records read from right to left, as indicated by the time at the bottom of the curve in Fig. 4. The vertical coördinate is in amperes, the full scale being 50 amperes. This cur-

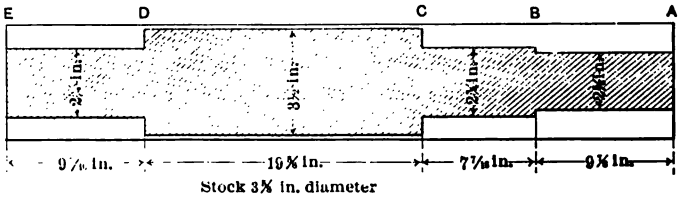


FIG. 5 SHAFT OF MACHINERY STEEL

rent at 220 volts corresponds to 11-kw. input to the motor. At the extreme right, the record indicates zero power; that is, the motor was standing idle.

129 During the interval marked "change," the stock to be turned was placed in the chuck of the lathe. At *a* the current increases for a

very short interval to about 3 amperes, while the lathe was running idle. The current then suddenly increases to about 30 amperes, due to the fact that the cutting tool was fed against the stock and the cut started. The current remains at this value for a period of about five minutes while the cut *AB* is taken, changing the diameter of the stock as indicated in Fig. 5. At *b* the current drops to three amperes, the motor running idle while adjustments of cutting tools are made. The current then increases to 28 amperes while the cut *BC* is taken. At *c* the machine is stopped to reverse the half-completed shaft for machining the opposite end. At *e* the machine is again started and the current increases to 27.5 amperes while the cut *ED* is taken. Another adjustment of the diameter is then made, the machine running idle for a short interval. From 8 to 10 amperes are required when the final cut *DC* is taken, after which the machine is stopped to remove the completed shaft. A similar record is produced when the next shaft is turned.

130 The record shows three completed cycles, covering the time required to complete three shafts. At 11.15 a.m., before taking the cut *ED*, there are sudden fluctuations of current; the form of the curve compared with other cycles shows clearly that some trouble was encountered with the cutting tool or work, and the adjustments made. The record also shows the delay in time.

TABLE I ANALYSIS OF TIME AND POWER OF A LATHE OPERATION

Shaft	Time	Mins. Amps.	Cutting *AB*	*BC*	*ED*	*DC*	Mins. %	Total Cutting	Change	Reverse	Adj. Tool	Misc.	Complete	Time Factor	Load Factor
1	7 30	Mins.	5.1	3.7	4.9	4.9	Mins.	18.6	5	5	12.0	21.2	61.8		
		Amps.	23	22	22	5	%	30	8.1	8.1	19.5			30	12
2	8 05	Mins.	5.3	3.9	4.4	4.4	Mins.	18.0	4.7	2.4	4.4		29.5		26
		Amps.	25	23	24	5	%	61	15.9	8.1	14.9			61	
3	8 30	Mins.	5 0	3.7	4.8	4.6	Mins.	18.1	7.5	2.4	1.9		29.9		
		Amps.	29	25	24	7	%	60.5	25	8	6.4			50.5	26.5
4	9 05	Mins	4 5	3.4	4.8	4.7	Mins.	17.4	3.2	8.9	2 3	27.1	31.8		
		Amps	31	29.5	24	6	%	54.8	10	27	7.2			54.8	25
5	10 05	Mins	5 1	3.8	4.5	4.7	Mins.	18.1	5	2.5	1.3		54.0		
		Amps	29	26	25	6	%	33.5	9.3	4.7	2.4			33.5	14.6
6	10 30	Mins	4.9	3.6	4.6	4.9	Mins.	18.0	4.3	2.4	2.0		26.7		
		Amps	28	25	25	5	%	67.5	16.1	9	7.5			67.5	25
7	11 00	Mins	5 0	3.7	5.4	5.1	Mins.	19.2	5.5	2.6	2.7		30.0		
		Amps	29	26	24	4.5	%	64	18 4	8.7	9			64	27

131 Table 1 is a summary of the data obtained from the graphic record, part of which is shown in Fig. 4. Observations of cutting

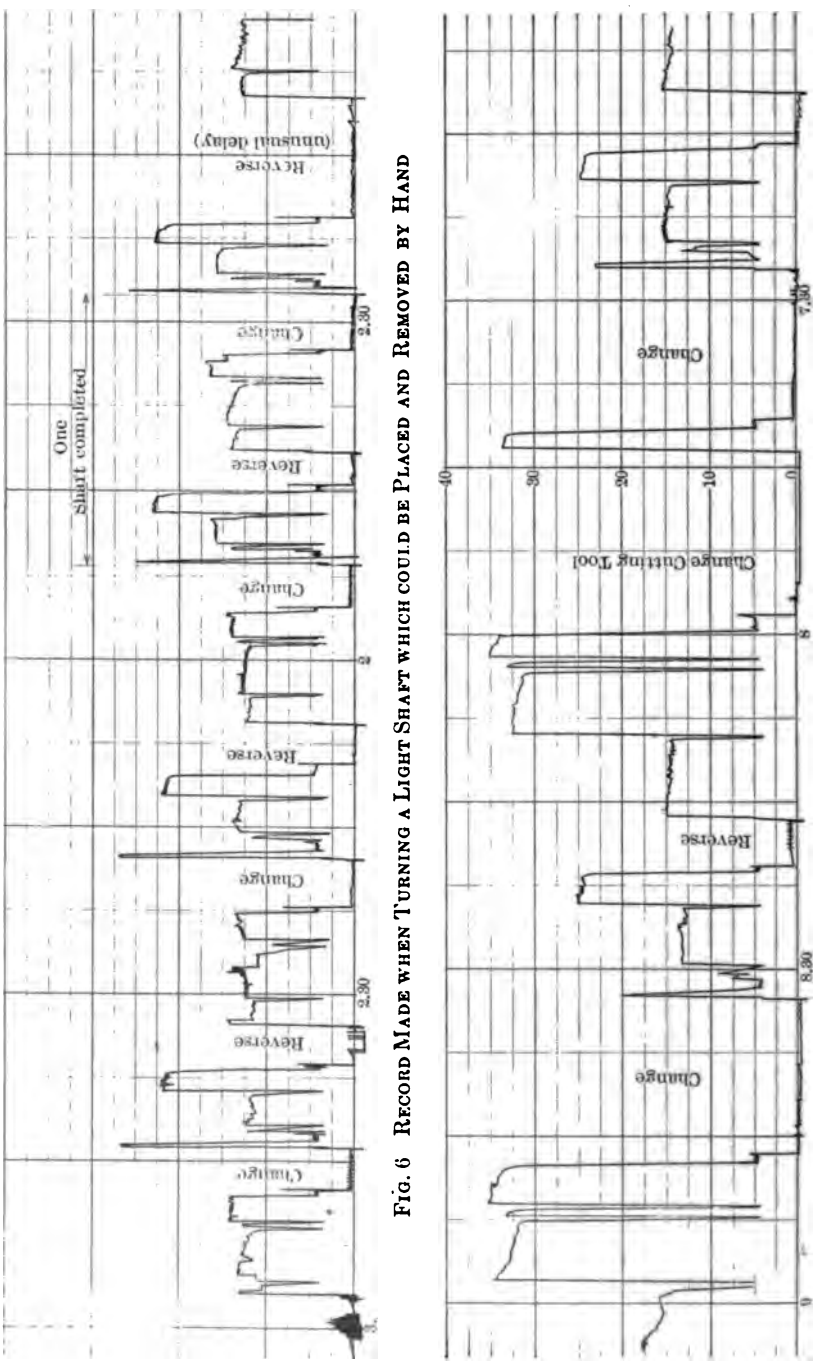


FIG. 6 RECORD MADE WHEN TURNING A LIGHT SHAFT WHICH COULD BE PLACED AND REMOVED BY HAND

speed and feed were taken at the lathe. The cutting speed used while turning these shafts was 55 to 60 ft. per min. The feed while taking the cuts *AB*, *BC*, and *ED* was 0.04 in. per revolution, and while taking cut *DC* was 0.077 in. per revolution. The normal time to complete a shaft was from 27 to 32 min. In case of shaft No. 1 the time was 62 min.; this was the first shaft turned after starting work, and preliminary adjustments, oiling lathe, etc., consumed 21 min.; 12 min. was required to adjust the cutting tool. In the case of shaft No. 5, 54 min. was required on account of a 27-min. delay. The amperes referred to in Table 1 are those below the 3 amperes required to run the machine idle; they are, therefore, a measure of the power required to remove the metal. The time factor averages 52 per cent; its maximum value is 67 per cent, and its minimum value is 30 per cent. The load factor is 25 per cent under normal conditions.

132 It must be obvious that, with a given rate of cutting, the fewer the delays, the higher will be the time factor. The magnitude of the records is an indication of the rate of removing metal, as will be further explained.

133 By means of this meter record it is possible to discover all delays, and to check the rate of cutting metal. Those are the two fundamental factors which determine the rate of output on machine tools. Any deviation from the standard cycle of operation is at once detected from the form of the record. Observations of cutting speed and feed need be taken in only one case. The record will not only show the deviation therefrom, but will also indicate whether the modification is an improvement or a drawback to the rate of output. Fig. 6 and Fig. 7 show two records taken on the same roughing lathe, operated by the same man, but turning two different shafts. The shaft turned while making the record shown in Fig. 6 was light, and could be removed and replaced in the lathe by hand. That turned when the curve in Fig. 7 was obtained was heavy, and required crane service. The greater intervals between cutting operations, so apparent in the case of Fig. 7, were due to delays in obtaining crane service to handle the heavy shaft.

134 Records taken during several days of operation showed an average of 5 min. longer time required for every change and reversal when made by crane. This condition was remedied soon after making the test, by installing a jib crane next to the lathe, and the time to complete the larger shaft was thereby reduced from 55 min. to 45 min., a saving in time and cost of about 20 per cent. The overhead charge against this tool (see Appendix 4) was 60 cents per hr., or $6 per 10-hr. day. The operator received $3.50 per day, making a total daily

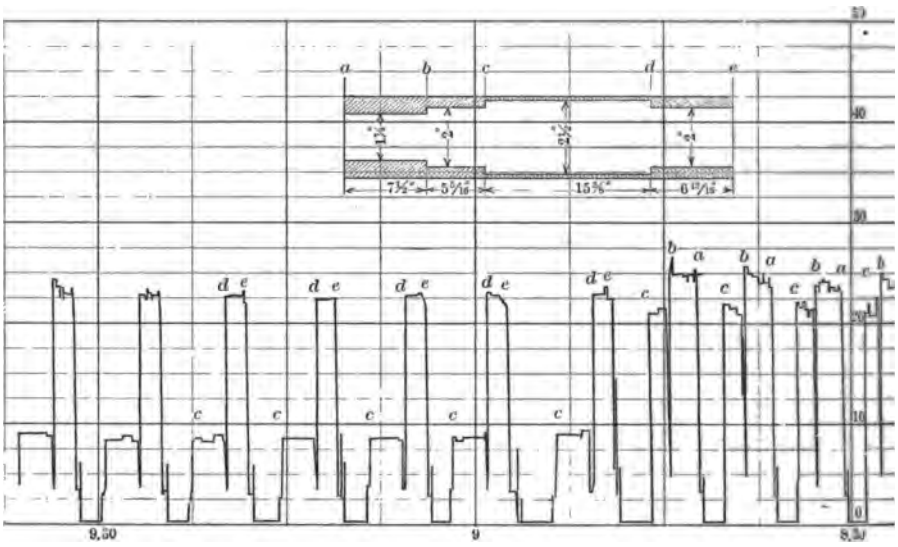


FIG. 8 RECORD WHEN TURNING THE SHAFT SHOWN IN THIS DIAGRAM

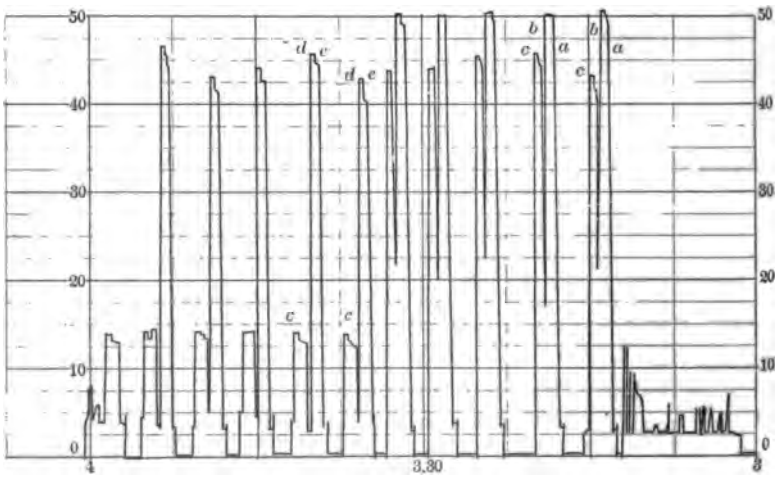


FIG. 9 RECORD WHEN TURNING THE SAME SHAFT AT DOUBLE THE CUTTING SPEED

expense of $9.50. Before the jib crane was installed ten shafts were completed per day, making the cost of actual labor and overhead tool charge $9.50 divided by 10, or 95 cents per shaft After the improvement, 12 shafts per day were completed with the same overhead charge, thus reducing the labor and overhead tool charge to 79 cents per shaft.

135 Such a delay seems self-evident, after it has been discovered, but in a large shop where everybody is busy small delays are easily overlooked. An automatic recording meter reveals delays caused by grinding and replacing tools, etc., besides those just indicated.

136 The elimination of delay, however, is not the only advantage to be obtained from the use of a recording meter. Fig. 8 and Fig. 9 are meter records which show rates of cutting on a shaft with the dimensions given in Fig. 8. In Fig. 8 the cutting speed was 50 ft. per min. The feed for cuts *AB*, *BC* and *ED*, was 0.05 in. per revolution, and for *DC* was 0.072 in. per revolution. The same feed was employed for corresponding cuts in Fig. 9, but the cutting speed was 100 ft. per min. It will be noted that the current above friction load in Fig. 9 is double that required for similar operations in Fig. 8. The saving in time is clearly shown. An analysis of records of this kind, taken over a period of several days, gives a means of determining the most economical feeds and cutting speeds to employ on a given operation.

TABLE 2 TIME FOR ROUGHING SHAFT, EXTREME CONDITIONS

	Average Condition		Best Conditions		Poorest Conditions	
	Minutes	Per Cent of Total Time	Minutes	Per Cent of Total Time	Minutes	Per Cent of Total Time
Removing and replacing shafts	6.0	38	2.8	23	14.9	50
Adjusting tool	1.7	11.0	1.4	12	6.7	22
Cutting	8.0	51.0	8.0	65	9.4	28
Total	15.7	....	12.2	....	30.0	.....

137 Table 2 shows the time relation between the various operations in roughing the shaft, outlined in Fig. 8. Approximately the same conditions were found with shafts of other characteristics. The time factor of lathe operation for this class of work is thereby shown to vary from 28 to 65 per cent, the average being about 50 per cent.

138 An investigation by personal observations over a short period of time often leads to erroneous results, as is shown by the following

experiments: In turning shafts on a roughing lathe, the first trial was with a cutting speed of 80 to 100 ft. per min., and a feed of 0.026 to 0.044 in. per revolution. In the second case, a cutting speed of 40 to 50 ft. per min. at a feed of 0.05 to 0.07 in. per revolution was employed. A single job could be completed in either case in 16 min., 12 min. being required for cutting. However, the average time per shaft, during several days' operation, was 22.6 min., with the higher speed, and 21.6 min. with the slower speed. The same number of cubic inches of metal per minute was removed in each case; but with the higher speed, more frequent regrinding of tools was necessary, resulting in more delays and giving the lower speed five per cent advantage in time saving.

SUMMARY OF THE USES OF THE GRAPHIC RECORDING METER

139 By means of the graphic recording meter, the following improvements in shop management can be effected:

a If individual motors are used to drive machine tools, the exact percentage of total working hours consumed in actual cutting can be determined; it is found to average from 40 per cent to 50 per cent, the maximum being as high as from 60 per cent to 65 per cent where the cut is of long duration; the minimum from 20 per cent to 30 per cent where jobs are short and the delay long in waiting for material, drawings, etc.

b The meter reveals all delays and suggests measures for eliminating those not essential and reducing all others to the minimum, thus materially increasing the time factor. All delays shown should be accounted for, and an attempt made to avoid them. Common delays are in assignment of the next job, in obtaining drawings, tools and other necessary materials, and in waiting for crane service.

c The rate of cutting indicated by the power consumption of motor-driven tools can be checked with a recording meter. The maximum rate is limited only by the nature of the work, and the strength of the machine tool and of the cutting tool.

d The rate for maximum economy can be determined for different classes of work; and the records, considered as standard, can be compared with other operations of the same

character to see whether the proper rates of cutting were used. In a finishing operation the rate depends upon the accuracy required. A record can be made while an expert machinist does the job, and this record should be referred to when other jobs of similar character are machined.

140 By the use of curve-drawing meters, and a careful study of the data obtained, the superintendent of a shop in which the individual motor-driven system is employed can set a limit fair both to employer and employees, for roughing, finishing, adjusting and setting-up. Different methods of doing the same job can be compared to determine which is the most efficient.

141 The graphic meter need not be located near the machine to which it is connected, but may be placed in the foreman's office. Small leads connected to a shunt, or to a series transformer, according to whether direct current or alternating current is employed, are all the wiring required. The wiring can be so arranged that the connections of the meter can be readily transferred to any one of several tools; thus a single meter can be made to serve a group, or any number of tools, depending somewhat upon the frequency with which the records are required.

142 So far we have dealt chiefly with the time required to do machining operation, time being a most important consideration with shop managers and those who use machine tools. The power consumption, however, is also of some importance, especially to those requiring motors for machine tool operation.

RELATIVE ECONOMY OF LINESHAFT DRIVE AND INDIVIDUAL MOTOR DRIVE

143 An increase in economy of operation of manufacturing machinery can be effected in two ways: first, by reducing the power required to operate the machinery, by saving of friction load, etc.; second, by reducing the time required for a given operation, or, in other words, increasing the output in a given time. When confronted with the problem of deciding between the continued use of an existing lineshaft drive, or an individual motor drive, or when deciding between the two methods for a new installation, the problem should be considered in all its phases, as outlined in Table 3. This table includes every important item to be considered, except one; and in every case the advantage is with the motor.

144 Comparing the first cost is possibly the first consideration to enter the mind of most men, and this is the one consideration omitted from Table 3. That this consideration is relatively of minor

TABLE 3 COMPARISON OF LINESHAFT DRIVE AND INDIVIDUAL MOTOR DRIVE FOR MACHINE TOOLS

	Item	Lineshaft Drive	Individual Motor Drive	Advantage of Individual Motor
1	Power consumption	Constant friction loss in shafts, belts and motor, power for cutting	Friction loss (motor and tool only); useful power only while working	Less power required
2	Speed control	No. speeds = no. cone pulleys × no. gear ratios	No. speeds = no. controller points × no. gear ratios	More speeds possible time saved in speed adjustments
3	Reversing	Clutch and crossed belt	Reversible controller	Time saved in reversing
4	Adjusting tool and work	Stopping at any definite point very difficult	Can be started in either direction and stopped promptly at any point	Time saved in setting up and lining up
5	Speed adjustment	Large speed-increments between pulley steps	Small speed increments between controller steps	Time saved by obtaining proper cutting speed
6	Size of cut	Limited by slipping belt; large belts hard to shift	Limited by strength of tool and size of motor	Time saved by taking heavier cuts
7	Time to complete a job	.....	....	Much less time required as indicated for previous items
8	Liability to accidents	Slipping or breaking belts; injury to machine tool; cutting tool or prime mover	Injury to machine tool, cutting tool or motor	Much less liability to accidents
9	Checking economy of operations	Close supervision required; very difficult to locate causes of delay	Accurate tests possible by means of graphic meter which records automatically all delays and rate of cutting	Causes of delay and remedies easily located without personal supervision
10	Flexibility of location	Location determined by shafting, and changes difficult	Location determined by sequence of operations; changes readily made	Greater convenience in handling and increased economy of operation; more compact arrangement possible

importance will be evident, when the saving in power consumption, and in time, made possible by individual motors, has been considered.

SELECTION OF MOTOR AND TOOL EQUIPMENT

145 In the selection of a motor-driven tool, there are certain features which should be taken into account and properly analyzed, and specifications drawn to cover them. If a tool is for specialized manufacturing:

a The exact class of work which the tool is to accomplish should be specified.

b If the power required to remove the metal is not known, then a statement should be made as to the approximate feed and cutting speeds to be taken.

c Careful ana'ysis should be made of the time required to load and unload the machine, to determine the feasibility of employing auxiliary means other than manual labor for loading the tools.

d From this information, an approximate determination should be made as to the intermittency of operation of the tool, in order to decide whether an intermittently rated motor or a continuously rated motor will be required.

e From a knowledge of the physical shape of the work, determination should be made as to whether an adjustable-speed motor will result in economy of time, if used on this particular class of tool.

f This will enable the tool builder to determine upon the proper type of controller, and its most desirable location from an operating point of view for the workman.

146 If a special type of tool is not desired and it is preferable to purchase one with such characteristics that it can be used for general manufacturing, one should determine as nearly as possible the range of material or work for which it will be used in straight manufacturing operations. This will undoubtedly permit of a better selection of motor and tool than the simple purchase of a standard stock tool.

147 It should be realized that under present schemes of operation few tools are in operation more than 50 to 60 per cent of the time, whereas the load factor of those tools may be as low as from 10 to 40 per cent. Thus we have it brought home to us clearly that much of the time the tool is in idleness and that it is often operated at much less than its maximum capacity.

148 The direct-current motors are built for speed adjustment over a range of 1 to 2, 1 to 3, and in some instances 1 to 4. With the proper selection of controller the speed adjustments may be made in small increments of from 10 to 15 per cent, and since these small increments of speed adjustment are available, it is essential that a controller be selected of such a type that it can be mounted conveniently to the operator, so that he may take full advantage of them.

149 Where it is necessary to employ the alternating-current motor, it may be absolutely essential to employ a gear box to obtain the various speed adjustments. When such a machine is employed, the fine gradation of speed obtainable with a direct-current adjustable-speed motor is absent, and the gear box will practically take the place of the ordinary cone pulley arrangement. It has, however, one advantage when motor-driven, and that is; that the tool is supplied with positive power at all times, and will take care of the maximum conditions without slipping or loss of power, which frequently occur when belt drive is used. In some instances it has been found possible to make good use of the so-called multi-speed alternating-current motor. This form of motor consists in certain different types of windings, permitting of a multiple method of pole grouping, such as, for instance, a speed of 1800, 1200, 900 or 720 r.p.m., according to the method of winding the motor. In some cases, this type of constant-speed motor when used in conjunction with a gear box, will permit of somewhat finer gradations of speed than are possible with a constant-speed alternating-current motor and a standard gear box.

150 While it is apparent that with the constant-speed motor all of the advantages of the adjustable-speed motor cannot be obtained, a tool equipped with either type has the advantage to be derived from the ability to obtain a graphic log of the time of operation of the tool. With either type, in combination with a graphic recording meter, a distinct gain can be made over a belt-driven tool from which such graphic curves cannot be conveniently obtained.

151 In Appendix 4 are the segregated charges which must in some manner be taken into account in determining the cost of a machine-tool hour, including not only the workman's time, but also the actual expense to a manufacturing establishment of having a tool equipped and ready to be used when the workman requires the service of such tool. Table 18 of this appendix will show the range of the tool hour rate, from which it is evident that it is far in excess of the labor rate for that tool; consequently, any time which can be saved in keeping the tool in its maximum productive capacity will far outweigh any

saving that can be made in the actual labor account. It is in this one feature that the motor-driven tool in combination with the graphic recording meter is destined largely to decrease the cost of machining operations when the records available by this combination are carefully studied and proper remedies applied.

GENERAL CONCLUSIONS

152 The economical operation of a machine shop requires a thorough analysis of all the operating costs, that is, overhead and operating charges of all kinds; and an accurate knowledge of the operating conditions of all machine tools. Investigations of these conditions must be conducted by someone familiar with both the engineering and the shop features of the apparatus manufactured. The investigator should also be familiar with the characteristics of the various types of motors and methods of control, in order that the most advantageous electrical equipment as well as the best machine tool equipment may be installed, with suitable tools for different sets of conditions.

153 Such investigations lead to the following improvements which result in increased productive capacity:

a More flexible arrangement of tools.

b Greater facilities for handling materials at the tools.

c Greater facilities for handling materials between tools.

d Better facilities for obtaining auxiliary material, drawings, tools, etc.

e Better facilities for making adjustment of the tools during machinery operation.

f Removal of causes of unsuspected or avoidable delays due to small accidents and improper characteristics of the drive.

g All lost time due to whatever cause, which can be avoided, is immediately brought to the attention of the superintendent, and an analysis of these losses will result in their elimination.

154 With motor-driven tools this analysis can be made much more conveniently and with less expense than can similar studies with any other form of machine-tool drive.

155 While in many shops there are elaborate systems of time keeping, with time clocks, etc., all of which are based on keeping an exact record of the workman's time and seeing that he works the maximum

or full shop time, yet the most important consideration in manufacturing with machine tools is that the tools shall operate their full capacity, on account of their greater hourly value.

156 In comment on this conclusion it may be said that our tests have not been confined to metal-working tools, etc. We have found similar conditions in the wood-working industries, to some extent in cement mills, steel mills, brass and copper rolling mills, to a less extent in the textile mills, where it is a supposition that every machine is running the maximum number of hours, and at its maximum load at all times; and in several minor industries, in which the information obtained is no less important, even though it may be different from that obtained with machine tools or metal-working tools, as ordinarily installed.

157 Certain it is, that a careful analysis and study of conditions which are conveniently possible in motor-driven establishments will greatly reduce the cost of operation, and it seems reasonable to suppose that the data here presented may serve some useful purpose in arousing an interest in these conditions.

158 We know that wherever the tests have been made, the conditions of operation have been very materially benefited, and feel without question of a doubt that many dollars have been saved on account of the knowledge available in the simple records taken from motor-driven machines.

159 The writer wishes to acknowledge his indebtedness to Mr A. G. Popcke, who made the tests and supplied some of the information contained in the paper, and without whose coöperation the information submitted would not be available.

LIST OF APPENDICES

160 The four appendices which supplement the paper pertain to the following subjects:

No. 1 The characteristics of various machine tools as shown by diagrams from recording meters.

No. 2 Data on the power required to remove metal under the conditions set forth in the appendix, together with convenient charts for determining the various factors mentioned.

No. 3 A summary of the average horsepower equipment for different types of tools and the approximate speeds of the motors, which are normally selected for this work. The figures given are for averag

conditions only and are not applicable to the heaviest types of tools. In some instances, also, the motors called for are larger than would be used for the tools of several years ago. The object of the figures is simply to indicate approximately the sizes of motors usually specified.

No. 4 Overhead charges and machine-hour rates.

APPENDIX NO. 1 POWER ANALYSIS OF MACHINE TOOLS

161 The results which follow were obtained from graphic meter records from certain machine tools under the conditions specified. These examples are given to show the characteristics of the power and the time factors that enter into the performance of machine tools of different types. (In connection with this Appendix see definitions of terms in Par. 34.)

VERTICAL BORING MILLS

162 In Fig. 11 is given a record from a 72-in. boring mill equipped with a 220-volt adjustable-speed motor, 780 to 1560 r.p.m., 8.5 h.p. (assumed input at full load 8.5 kw.), taken while the tops of bronze discs were turned off and bored out. The vertical lines at frequent intervals show where the motor was started and immediately stopped, in order to make adjustments

TABLE 4 OPERATING CONDITIONS OF 72-IN. VERTICAL BORING MILL

Test No.	Time Factor %	Average Running Load		Max. Load		Avg. Kw. per Hr.	Load Factor
		Kw.	% Full load	Kw.	% Full load		
1	35	1.8	21	7.7	90	0.63	7.5
2	56	2.0	24	8.8	103	1.1	13.5
3	62	2.8	33	8.8	103	1.7	20.5
4	46	2.8	33	6.6	78	1.3	15.
5	28	2.2	26	7.7	90	0.62	7.5
6	37	2.2	26	8.3	98	0.81	9.5
Avg.....	44	2.3	27	8.0	94	1.00	12.

by moving the table of the boring mill a short distance. The gradual decrease in power after 9 a.m., and also after 3 p.m., shows improper use of the controller. The tool was fed towards the center of the mill, thereby gradually decreasing the diameter of the work. The motor was evidently allowed to run at a constant speed, while the speed should have been gradually increased to compensate for decreased diameter of work, and thereby keep the cutting speed constant. The controller was arranged to give the required speed adjustment, and failure to take advantage of this feature caused loss of time. In one

instance the records showed that 10 min. was consumed for an operation which could have been performed in 6 min., if the cutting speed had been kept constant, a saving of 40% in this operation. In another case, the time taken was 15 min., and would have been 9.5 min. with a constant cutting speed, which would have resulted in a saving of 37%.

163 While taking roughing and finishing cuts on this boring mill, from castings of motor frames, brackets and end plates, the conditions were found to be as in Table 4, from which the following summary is obtained:

Average time factor.....44%
Average running load .....2.3 kw., or 27% of full load
Maximum load, sustained for several minutes..8 kw., or 94% of full load
Maximum load peak .....8.75 kw., or 103% of full load
Average load .....1 kw., load factor 12%

RADIAL DRILLS

DRILLING AND COUNTERBORING

164 Table 5 was made up from records taken upon a 10-ft. radial drill driven by an induction motor of 7½ h.p., 720 r.p.m., obtained when cast-steel pole shoes were counterbored, as indicated in Fig. 10.

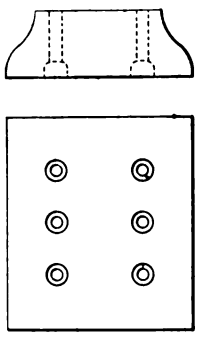
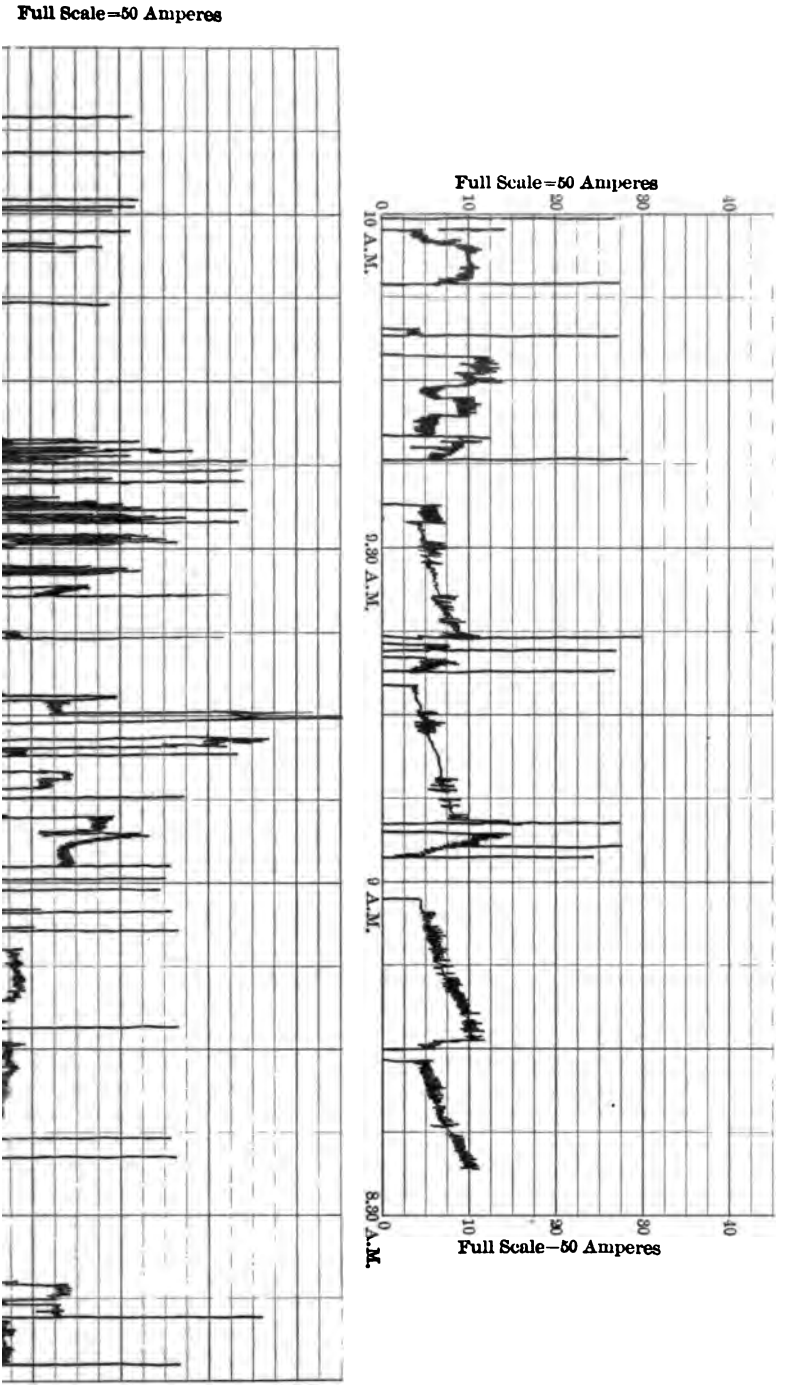


FIG. 10 POLE SHOE, DRILLED AND COUNTERBORED

165 The record (not here printed) shows 7½ min. per pole shoe, required to counterbore each of the six holes. The sum of these is about 44 min. The total time for adjusting the drill, given under column headed "Adjustment," was from 15 to 24 min. for each pole shoe. The time consumed in removing and replacing the shoes in the clamps is tabulated under column headed "Change." This ranged from 7½ min. to 10 min. The time to complete counterboring each pole shoe varied from 70 to 75 min. The actual cutting or drilling time was from 57 to 64% of the total time to complete a pole shoe. From 10 to 14% of the time was consumed in changing the shoes, and from 22 to 33% was consumed in adjusting the drill. The average power consumed was 2.8 kw., making a load factor of about 37%.


Full Scale=50 Amperes
Full Scale=50 Amperes
0
10
20
30
40
10 A.M.
9.30 A.M.
9 A.M.
8.30 A.M.
0
10
20
30
40
Full Scale—50 Amperes
Full Scale=50 Amperes

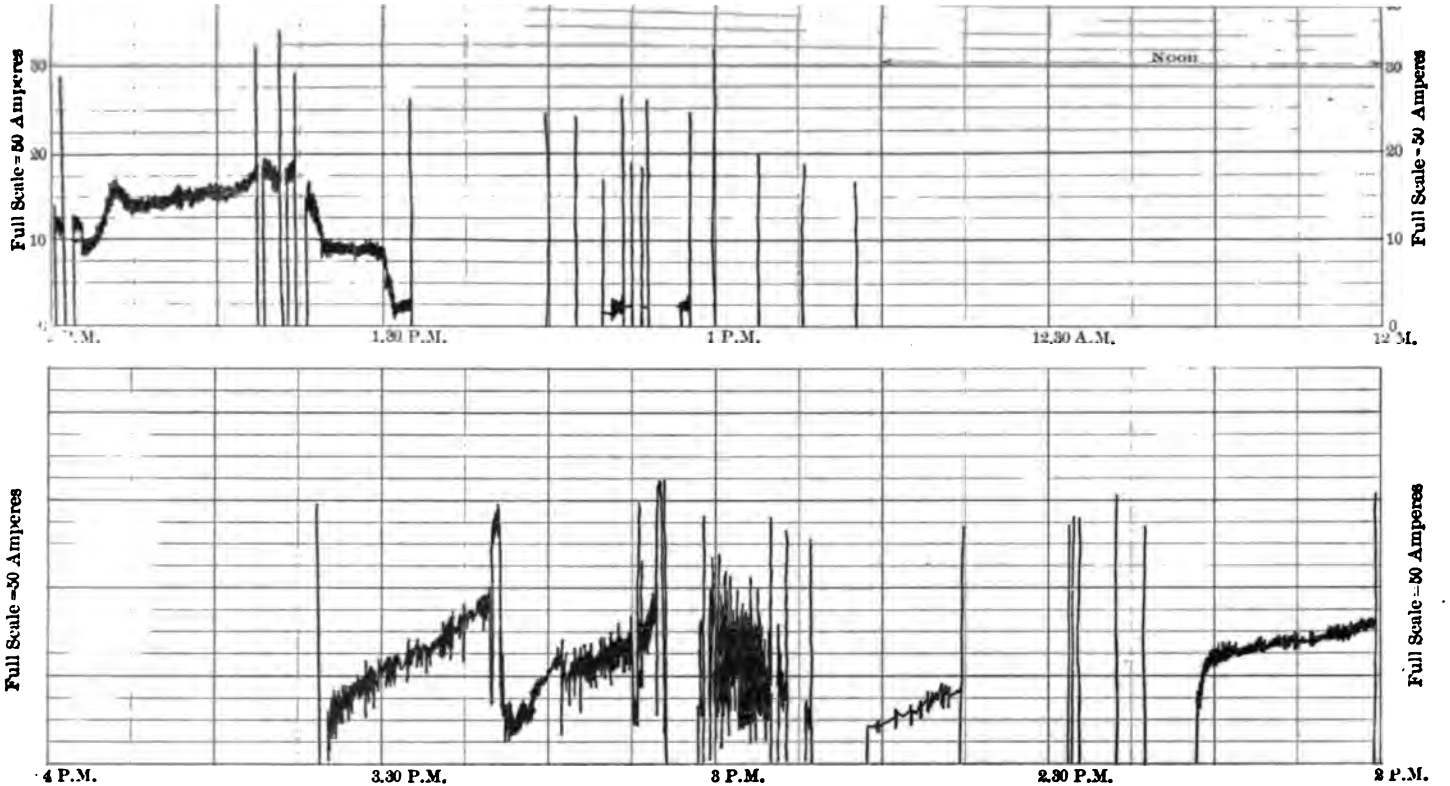


FIG. 11 COMPLETE METER RECORD FOR ONE DAY FROM 72-IN. BORING MILL

TABLE 5 ANALYSIS OF A COUNTERBORING OPERATION

	Number of Hole						Total Time to Drill	Adjustment	Change	C p
	1	2	3	4	5	6				
Min.	7.3	7.5	7.4	7.5	7.4	7.5	44.6	19.6	8.2	
% of Total							61.5	27.2	11.3	1
Min.	7.1	7.4	7.3	7.4	7.4	7.4	44	17.7	8.4	
% of Total							62.8	25.2	12.0	1
Min	7.5	7.5	7.5	7.3	7.4	7.5	44.7	15.5	9.9	
% of Total							64	22	14	1
Min	7.3	7.1	6.8	7.0	7.1	7.5	42.8	24.2	7.5	
% of Total							57.5	32.5	10	1

Drill with no load, 1.75 kw. Power to drill, 1.75 kw. Average running load, 2.8 kw.

TABLE 6 ANALYSIS OF DRILLING AND TAPPING OPERATION

Set up equals 56 min.

Pole No.	Operation	Time Required, Minutes Hole No.						Total Time Requ		
		1	2	3	4	5	6	To Drill	To Adjust Drill	To Change Drill
1	1 9/16-in. drill	1.1	1.3	1.1	1.3	1.3	1.3	7.4	5.6	.....
	1 33/64-in. drill	4.5	4.2	4.4	4.3	4.2	6.6	28.2	6.0	8.3
	1 1/8-in. tap	0.9	0.6	0.7	0.7	0.5	0.8	4.2	13.2	6.6
							Total min.	39.8	24.8	14.9
							% of total	50	31.2	18 8
Turn Over = 26.2 min.; delay for drawing = 31.4 min.; other delay = 57										
2	1 9/16-in. drill	1.4	1.3	1.3	1.1	1.2	1.1	7.4	6.3	.....
	1 33/64-in. drill	5.0	4.8	4.8	4.6	4.9	4.6	28.7	8.2	.....
	1 1/8-in. tap	0.9	1.1	1.1	1.1	1.1	1.1	6.4	30.5	12.5
							Total min.	42.5	45.0	12.5
							% of total	42.5	45.0	12.5
Turn Over = 21.2										
3	1 9/16-in. drill	1.7	1.3	1.5	1.2	1.5	1.2	8.4	4.4	.....
	1 33/64-in. drill	4.9	5.1	5.6	5.4	5.4	4.7	31.1	.....	3.8
	1 1/8-in. tap	0.6	0.8	0.6	0.8	0.8	0.6	4.2	14.3	8.4
							Total min.	34.7	18.7	12.2
							% of total	53	28	19

DRILLING AND TAPPING

166 Table 6 is from a record made while an 8-pole revolving field was drilled and tapped for fitting pole shoes. To place the job in position required 56 min., owing to lack of prompt crane service. No lining-up was required; the work was simply set upon the bed plate of the radial drill.

167 The total time consumed in adjusting the drill to proper position per pole was 5.6 min. The $1\frac{9}{16}$-in. holes were first drilled $\frac{3}{4}$-in. deep, requiring about 1.2 min. each, a total time for drilling the six holes of 7.4 min. The $1\frac{1}{16}$-in. drill was then removed and replaced by a $1\frac{9}{32}$-in. drill, the change requiring about 8 min. To drill each $1\frac{9}{32}$-in. hole $2\frac{1}{2}$ in. deep took about $4\frac{1}{2}$ min., or 28 min. for the six holes. Adjustments of the drill took 6 min., making a total time of $42\frac{1}{2}$ min. to complete drilling the six $1\frac{9}{32}$-in. holes. The drill was then removed and a $1\frac{5}{16}$-in. tap substituted, this change requiring 6.6 min. To tap each hole took from 0.6 to 0.9 min., making a total of 4.2 min. for the six holes. The time taken for adjustments was 13.2 min., making a total of 24 min. for the tapping operation. The actual cutting time for tapping was $17\frac{1}{2}$% of the total time. The total cutting time per pole, including one tapping and two drilling operations, was 50% of the total completing time, 31.2% of the time being consumed in adjusting, and 18.8 % in changing drills for taps. About 20 to 30 min. was consumed in waiting for a crane to turn over the job in order to drill the next pole piece. The time required to complete the job can be analyzed as follows:

Set up and wait for crane	56 min.
Complete poles	560 min.
Turn over (crane service)	240 min.
Total	856 min., or 14 hr. 16 min.
Total cutting time	320 min., or 5 hr. 20 min.
Time factor	38%

RECORDS FROM 5-FT. RADIAL DRILL

168 The following results were obtained by taking records on a 5-ft. radial drill driven by a $7\frac{1}{2}$-h.p. adjustable-speed motor, with rated speeds ranging from 400 to 1600 r.p.m., while drilling a series of holes in a large steel casting. Out of $11\frac{1}{2}$ hr., 4 hr. 42 min. was consumed in actual drilling, the other 6 hr. 48 min. being required to make adjustments. In this case, the time factor was 41%. The average running load while drilling was 1.5 kw., making an average daily load of 0.7 kw., or a load factor of 10%.

169 While drilling a series of 22 holes, 67.5% of the time was consumed in actual drilling, the remaining 32.5% being consumed in moving the drill from one position to the next. In another case where holes were to be drilled and tapped, 74.5% of the time was consumed in actual drilling; while in tapping the holes, the machine was in use 44% of the time, the remainder being consumed in making adjustments. Records taken while a series of small jobs was drilled show that the time factor was as low as 20%, much time being lost in obtaining drawings and auxiliary materials.

PORTABLE MILLING MACHINE

170 On a portable milling machine driven by an induction motor of 3 h.p., 720 r.p.m., while milling slots and dovetails in an iron casting, the averag running load was 1.5 kw. to 2 kw., giving a load factor of from 50 to 67%. Th time factor was 54%. 24% of the total time was required to make adjustment of the cutting tool; the remaining 22% was required to set up the job, that is to place the portable machine in a central position upon a table inside th circular casting where the machine could be completely revolved and clea the inside of the frame.

PORTABLE SLOTTER

171 On a portable slotter driven by a 10-h.p., 720-r.p.m. motor while cut ting slots in a cast-iron frame, the arm carrying the cutting tool is moved u and down by reduction gearing and a rack. The cut is taken on the up-stroke The record (not printed) shows that the peak load occurs just before the cu is taken, i.e., when the arm is reversed for the upward motion; the minimur load occurs on the downward stroke. The record also shows a variatio in the amount of power required to produce the cut. This variation i due to irregularities in the feeding mechanism on the machine tested, a ratche of which had become worn. The time factor was 50% and the load factor 12%

COMPARISON OF MILLING AND SLOTTING

172 From the results obtained an interesting comparison can be draw between the time required to cut slots with a miller and with a slotter, as show in the following table:

	Size of Slots Inches	Cutting Time Minutes	Minutes to C 1 In.
Miller	7½ x ¾ x 12½	11.8	0.95
Slotter	7½ x ¾ x 15½	8.4	0.53

173 The results show that the actual cutting time per inch of the slotter i but 56% of the time of the miller; both were removing exactly the same amoun of material. The curves also show that the intervals required for adjustmen of the positions of the tools from one slot to another averaged 6.1 min. on th miller and 3.1 min. on the slotter, an advantage of 50% again in favor of th slotter. The time to set up the work must be included in order to determin the relative advantage of one machine over the other. The setting-up tim was found to depend more upon the work than upon the tool, and neither too had an advantage. Two hours was required to set up the job on each too The results may then be summarized by comparing the operations of the ma chines in cutting two similar jobs of 12 slots 10 in. long:

	Setting Up Time	Adjustments	Cutting Slots	Total
Miller.....	2 hr.	1 hr. 12 min.	1 hr. 44 min.	4 hr. 56 min.
Slotter.....	2 hr.	0 hr. 36 min.	1 hr. 4 min.	3 hr. 40 min.

174 This shows that the total time required by the slotter was but 74% of that required by the miller; a saving of 1 hr. 16 min. on every such job.

POWER REQUIRED TO OPERATE PLANERS

175 Table 7 contains a summary of results to determine the power required to operate various motor-driven planers. The average time factor in ordinary planing operations is about 50 to 60%.

TABLE 7 ANALYSIS OF POWER REQUIRED TO OPERATE PLANERS

Size Planer	H.P. of Motor	Reversal a		Reversal b		Cutting Stroke		Reverse Stroke		No Load	Average Running Load		Load Factor at 50% Time Factor
		Kw.	% Full Load	Kw.	% Full Load	Kw.	% Full Load	Kw.	% Full Load		Kw.	% Full Load	
36 in. x 12 ft.	15	8.5	56	6.5	43	2.5-5	17-34	3	20	2	4-5	30	15
7 ft. x 12 ft.	15	6	40	3	20	1-2	7-14	0.75	5	0.6	4	25	12.5
14 ft. x 20 ft.	30	34	113	30	110	6-19	20-34	8	27	5.5	11	35	17
10 ft. x 20 ft.	50	22	45	16	30	12-16	25-32	7	14	4.5	16	30	15
14 ft. x 30 ft.	40	40	115	24	60	10-16	25-40	10	25	5	15	36	18

Reversal a, from cutting to return stroke.
Reversal b, from return to cutting stroke.

CURVES FROM MACHINES IN A STEEL TUBE MILL

176 Fig. 12 shows a curve taken from a motor operating welding rolls while lap welding 5-in. tubes. The rolls were driven by a 150-h.p. induction motor. To reduce the peak load thrown on the motor, the rolls were equipped with a 5-ft. diameter, 5000-lb. flywheel. This record is interesting, in that it shows that a friction load of 12 kw. was required about 91% of the time, under which condition of operation the motor, on account of its light load, was operating at a power factor of about 30%, which is an undesirable condition for the power plant.

177 The duration of peak load is in each instance about eight seconds, which amounts to only about 9% of the total cycle of operation. During this period the input to the motor was from 128 to 160 kw. A study of the records shows that a smaller motor should be installed. The motor should be designed with a larger slip, or drop-in speed between no load and full load, so that with a some-

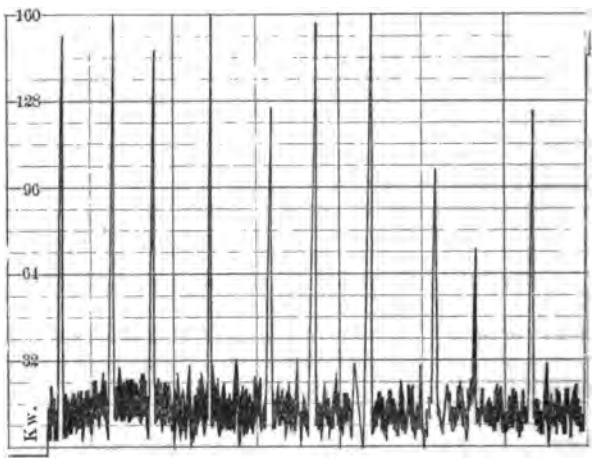


FIG. 12 RECORD FROM WELDING ROLLS EQUIPPED WITH FLYWHEI

what larger flywheel, when the load is steadily thrown on the motor, it slow down, allowing the flywheel to give forth energy and in this way n out or lowering the peaks for instantaneous demand for current from th With a smaller motor the power factor would be increased, the effi improved, and the load factor also improved. At the time the tests were a meter was used, having a paper speed of 24 in. per hr. The record show tubes were rolled at the rate of 40 per hour.

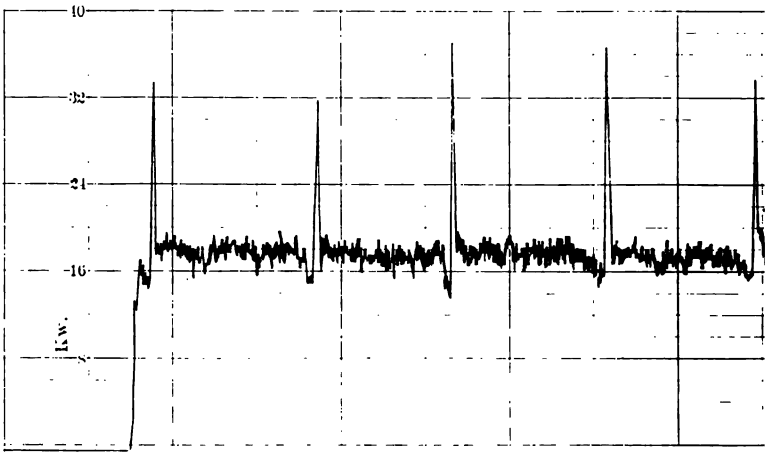


FIG. 13 RECORD FROM HOT-ROLL SCARFER

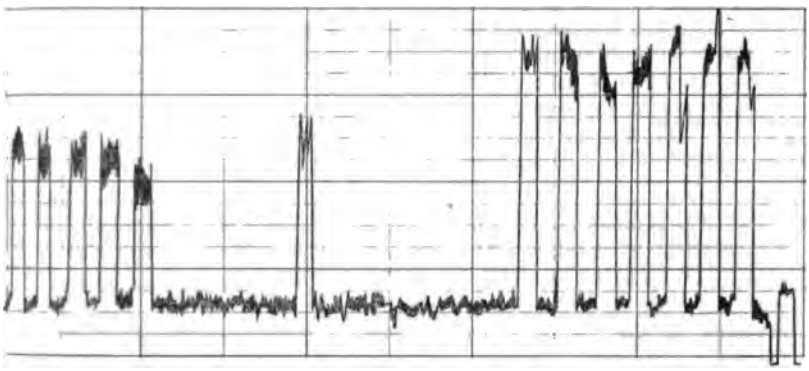


FIG. 14 RECORD FROM SHEAR SCARFER

178 The curve represented by Fig. 13 was taken from a 75-h.p. motor, operating a hot-roll scarfer, scarfing sheets for 12-in. lap-welded tubes. It shows that the friction load of 18 kw. is practically constant for about 90% of the time, and that the maximum or peak load of about 34 kw. occurred for about 4% of the total time. At the time these records were taken the meter was operating at a speed of 24 in. per hr., and the rolls turning out 10 and 15 tubes per hour. The difference in peak load is due to the fact that an increase in width of the metal causes a slight increase in power. Undoubtedly a 50-h.p. motor would have been satisfactory for this work with much more economy than the installed motor.

179 The curve represented by Fig. 14 is a record showing the operating conditions of a 50-h.p. induction motor driving a shear scarfer. On this curve

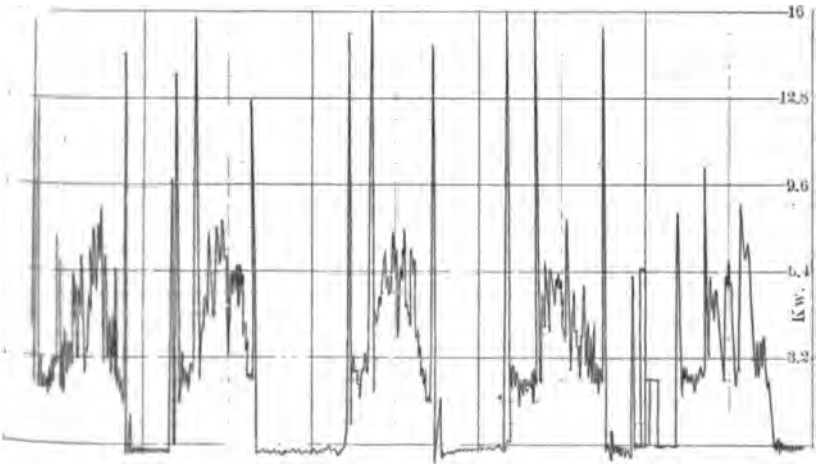


FIG. 15 RECORD FROM PIPE CUTTING-OFF MACHINE

the friction load was shown at about 2.3 kw., of a duration of 55% of the time The peak loads require from 10 to 13 kw. for the balance, or 45% of the time As the duration of the peak is only about 34 seconds, a smaller motor of abou 25 h.p. would be of sufficient capacity to do the work. In this instance, as i the others, a meter having a 24-in. movement of the record was used.

PIPE CUTTING-OFF MACHINE

180 The record shown in Fig. 15 was taken from a 5-h.p. motor operating pipe cutting-off machine, cutting 18-in. tubes at an average cutting speed o about 38 ft. per min. It will be noted that about 16 kw. were required fo starting, while the average load during cutting was about 6 kw. The motor wa reversed for the reaming operation, and the peak was very large, going o the scale. To start the machine the motor was again reversed, such manipu lation causing very severe overloads on the motor and the gearing to th machine. For a reversing operation of this nature an induction motor havin a large slip would be desirable, or a slip-ring type of motor, thus reducing th demand upon the line. A direct-current motor, if used, should be supplie with very heavy compound winding.

APPENDIX NO. 2 POWER REQUIRED TO REMOVE METAL

181 The power required to remove metal depends upon the nature of the cutting tool and the amount of metal removed per minute. Cutting tools may be divided into three general classes: (*a*) lathe tool type; (*b*) drills; (*c*) milling cutters.

LATHE TOOL TYPE

182 The lathe tool is used on lathes, boring mills, planers, shapers and slotters. Tests show that the power required by a tool of this kind when removing metal depends upon the cutting angle of the tool and the number of cubic inches of metal removed per minute. From observation and data

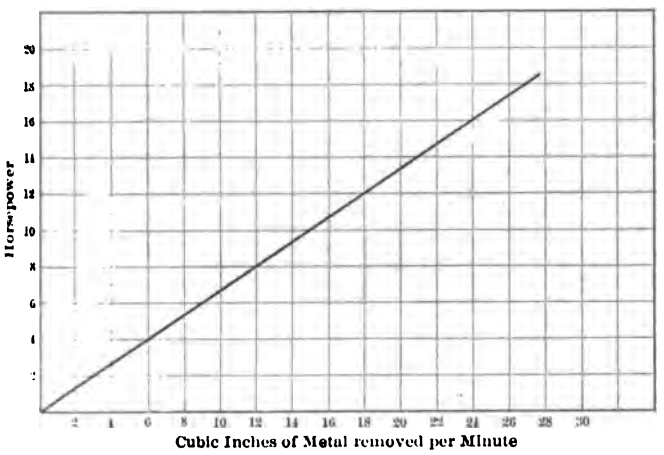
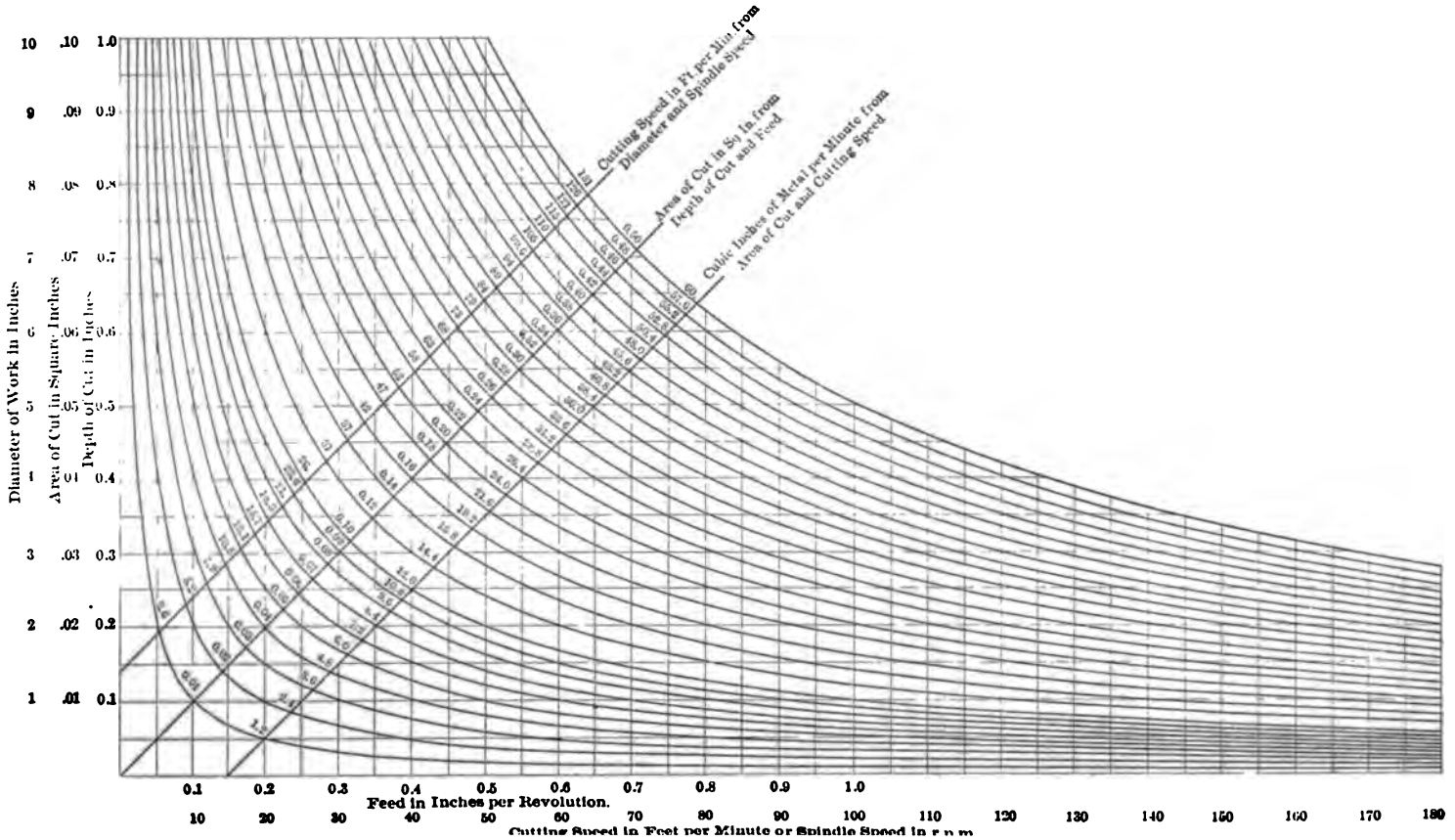


FIG. 16 RELATION BETWEEN HORSEPOWER AND CUBIC INCHES METAL REMOVED; MILD STEEL, 0.40% CARBON

obtained by means of the graphic recording meter, and the use of tools having a cutting angle of about 75 deg. to 80 deg. the curve shown in Fig. 16 was obtained. The results were independent of the cutting speed, feed and depth of cut, and show that a definite relation exists between the horsepower required to remove metal and the number of cubic inches removed per minute. The cubic inches of metal removed per minute were found to be as follows:

Area of cut(sq. in.) × cutting speed (ft. per min.) × 12, where
area of cut(sq. in.) = depth of cut(in.) × feed (in. per revolution)


Diameter of Work in Inches
Area of Cut in Square Inches
Depth of Cut in Inches
Cutting Speed in Ft per Min from Diameter and Spindle Speed
Area of Cut in Sq In from Depth of Cut and Feed
Cubic Inches of Metal per Minute from Area of Cut and Cutting Speed
Feed in Inches per Revolution.
Cutting Speed in Feet per Minute or Spindle Speed in r p m

DIRECTIONS FOR USING FIG. 17

a To find cutting speed: From intersection of horizontal line corresponding to diameter and vertical line corresponding to spindle speed, follow nearest curve and use value found in oblique line of figures marked cutting speed.

b To find area of cut: From intersection of horizontal line corresponding to depth of cut and vertical line corresponding to feed, follow nearest curve and use value found in oblique line of figures marked area of cut.

c To find cubic inches of metal removed per minute: From intersection of horizontal line corresponding to area of cut and vertical line corresponding to cutting speed follow nearest curve and use value found in oblique line of figures marked cubic inches of metal removed per minute.

To use curve, knowing diameter of work, spindle speed, depth of cut and feed, find cutting speed from (*a*), area of cut from (*b*), and cubic inches of metal removed per minute from (*c*).

183 The horsepower required to remove metal with the tools ordinaril ployed can be expressed by:

$$\text{h. p.} = \text{a constant} \times \text{cu. in. removed per min.}$$

The constant varies with the kind of metal removed.

184 In order to estimate the amount of power required to remove a amount of metal per minute the graphic method shown in Fig 17 has bee signed. This diagram is a multiplication table; those familiar with an cal geometry will recognize the equilateral hyperbola whose equation, ref to its asymptotes, is xy = constant.

185 To determine the cutting speed the usual procedure is as follows:

$$\text{cutting speed (ft. per min.)} = \frac{\pi \times \text{diameter} \times \text{r.p.m.}}{12}$$

$$= \text{constant} \times \text{diameter} \times \text{r.p.}$$

In the diagram each hyperbola corresponds to a given cutting speed. Tl ordinates of all diameters and spindle speeds producing the same speed sect on the same hyperbola. The cutting speed corresponding to any dian rotation at any number of r.p.m., is found indicated on the hyperbola pa through the intersection of the coördinates corresponding to the given v of diameter and r.p.m.

186 In a similiar manner an area corresponding to any depth of cut in i and feed in inches is obtained, and also the cubic inches of metal remove minute can be determined from the area of cut and the cutting speed. Tl rections for using the diagram are given in connection with it.

187 With the cutting tools ordinarily employed the following values been found by tests to exist for the horsepower required to remove 1 c of the following metals, per min.:

Brass and similar alloys	0.2 to 0.3
Cast iron	0.3. to 0.5
Wrought iron Mild steel (0.30%-0.40% carbon)	0.6
Hard steel (0.50% carbon)	1.00 to 1.25
Very hard tire steel	1.50

188 It must be remembered that these constants represent general av conditions; considerable variation may occur where special cutting tool used and special grades of metal are encountered.

LATHES

189 The following examples will explain the application of the diagram 17, to lathe work.

Example:	Diameter of work	= 5.5 in.
	Spindle speed	= 45 r.p.m.
	Depth of cut	= 0.45 in.
	Feed per revolution	= 0.06 in.

190 Find the intersection of the horizontal line through 5.5 in. diamet work, and the vertical line through 45 r.p.m. spindle speed. The curves

sing nearest this intersection correspond to a cutting speed of 63 and 68 ft. per min., indicating by interpolation a cutting speed in this case of 65 ft. per min. The area of cut, with depth of cut 0.45 in. and feed 0.06 in. is 0.027 sq in. The cubic inches of metal removed per minute, corresponding to an area of cut 0.027 sq. in. and a cutting speed of 65 ft. per min., is determined by finding the intersection of the horizontal line passing through 0.027 sq. in. area of cut and 65 ft. per min. This intersection is between the curves corresponding to 19.2 and 21.6 cu. in., showing that about 20 cu. in. of metal are removed per min. If the metal removed is wrought iron, the horsepower required is $0.6 \times 20 = 12$ h.p. If 0.50% carbon steel is turned, $1.00 \times 20 = 20$ h.p., is required. Brass would require $0.25 \times 20 = 5$ h.p.

BORING MILL

Example:	Diameter of work	= 45 in.
	Speed of table	= 4.5 r.p.m.
	Depth of cut	= 0.25 in.
	Feed	= 0.10 in. per revolution

191 The diameter of work goes only to 10 in. in the vertical column of the diagram. These may be multiplied by 10, and if used with the spindle speeds as they stand, the results in the oblique column of cutting speeds must be multiplied by 10. In case of large diameters the spindle or table speeds are usually low. The simplest way to use the diagram in these cases is to interchange *diameter of work and spindle speed*, i.e., assume that the diameter of the work is 10, 20, 30, etc., in the horizontal column, and the table speed under 1, 2, 3, etc., in the vertical column. In the problem under consideration the cutting speed is as follows:

192 The intersection of the horizontal line through 4.5 and the vertical line through 45 corresponds to a cutting speed of 52 ft. per min. The area of cut is 0.025 sq. in. The intersection of the horizontal line through 0.025 sq. in. area of cut, and the vertical line through 52 ft. per min. cutting speed lies between curves representing 14.4 and 16.8 cu. in., indicating that 15 cu. in. are removed per min. If cast iron of a soft quality is removed the power required for cutting will be $15 \times 0.3 = 4.5$ h.p. If the cast iron is of hard quality, $0.5 \times 15 = 7.5$ h.p., will be required.

SHAPER OR PLANER

Example:	Depth of cut	= 0.75 in.
	Feed per stroke	= $\frac{1}{16}$ in.
	Cutting speed	= 45 ft. per min. (from characteristic of planer or shaper)

Area of cut = $0.75 \times \frac{1}{16} = 0.046$ sq. in.

193 The cubic inches of metal removed per minute, corresponding to an area of cut of 0.046 sq. in., and a cutting speed of 45 ft. per min., is 24. The power required for cutting in the machine a hard grade of cast iron will under these conditions be $24 \times 0.5 = 12$ h.p.

194 In a planer the power required for reversing is usually considerably more than that required to cut metal, depending upon the design of the reversing

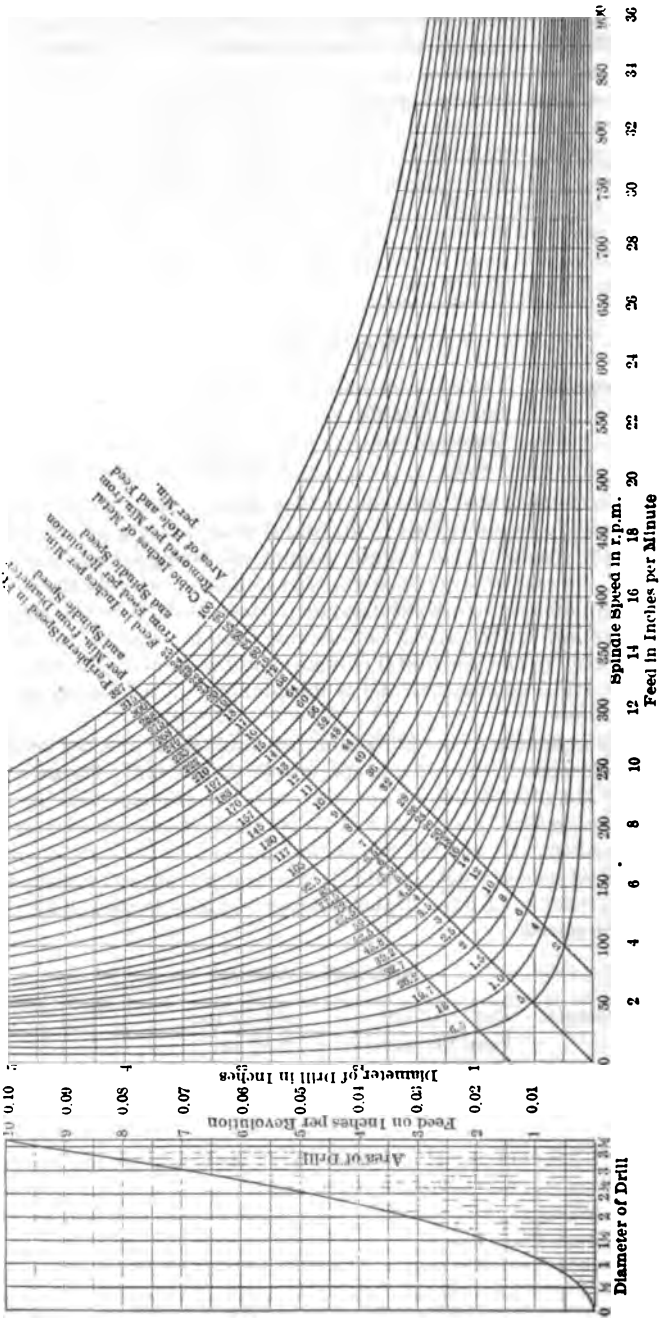


FIG. 18 MACHINE TOOL CALCULATOR FOR DRILLS

DIRECTIONS FOR USING FIG. 18

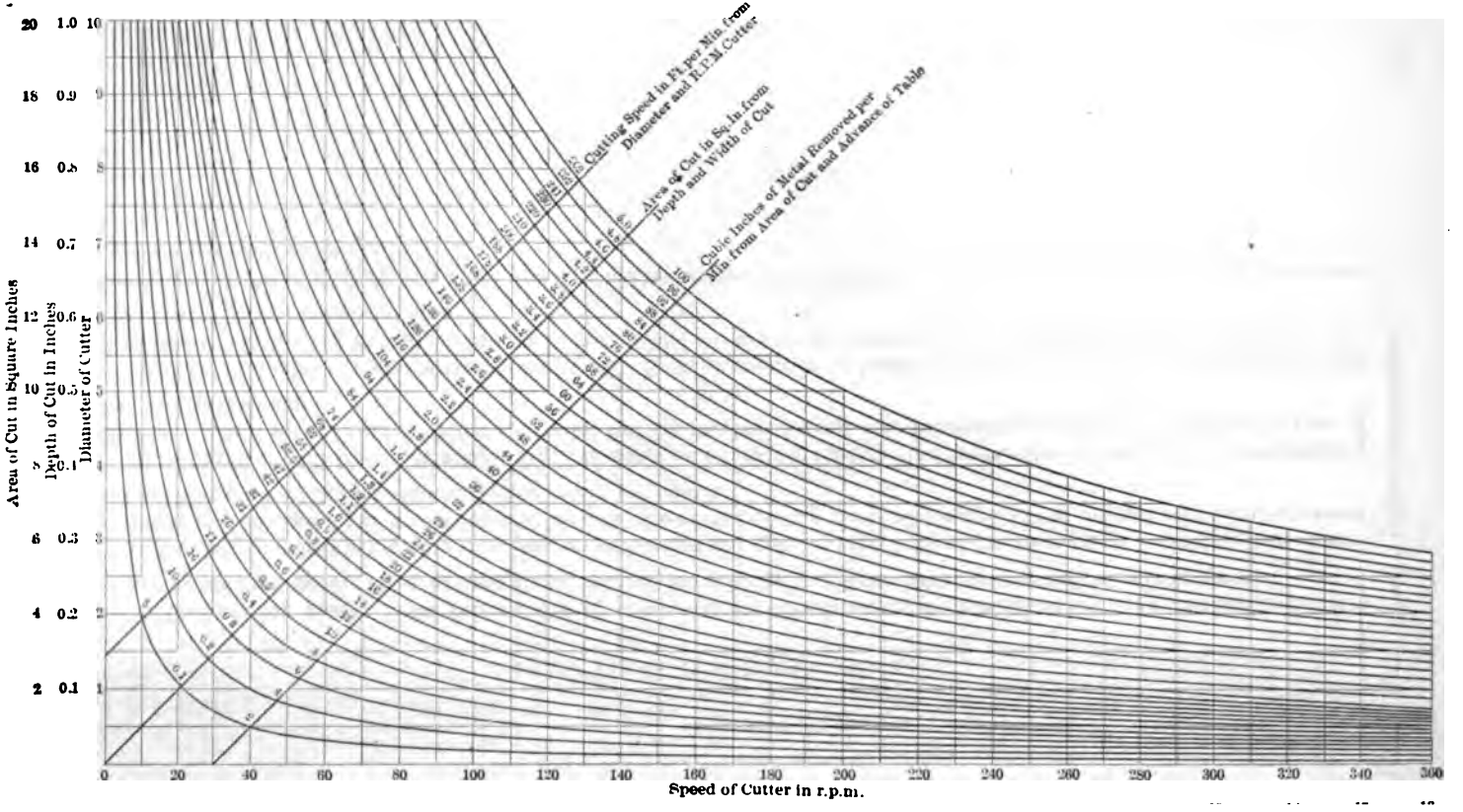
a To find cutting speed: From intersection of horizontal line corresponding to diameter of drill and vertical line corresponding to spindle speed, follow nearest curve and use value found in oblique line of figures marked cutting speed.

b To find feed in inches per minute from feed per revolution and spindle speed: From intersection of horizontal line corresponding to feed in inches per revolution and vertical line corresponding to spindle speed follow nearest curve and use value found in oblique line of figures marked feed in inches per minute.

c To find area of drill from diameter of drill use curve on left side of figure: Find intersection of vertical line corresponding to diameter of drill with the curve, follow the horizontal line passing through this intersection and obtain area under area of drill in vertical column.

d To find cubic inches of metal removed per minute: From intersection of horizontal line corresponding to area of drill and vertical line corresponding to feed per minute follow nearest curve and use value found in oblique line of figures marked cubic inches of metal removed per minute.

Knowing diameter of drill, spindle speed and feed per revolution, find cutting speed from (*a*), and cu. in. metal removed per minute from (*b*), (*c*) and (*d*).


Area of Cut in Square Inches
Depth of Cut in Inches
Diameter of Cutter
Cutting Speed in Ft. per Min. from Diameter and R.P.M. Cutter
Area of Cut in Sq. In. from Depth and Width of Cut
Cubic Inches of Metal Removed per Min from Area of Cut and Advance of Table
Speed of Cutter in r.p.m.
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360

DIRECTIONS FOR USING FIG. 19

a To find cutting speed: From intersection of horizontal line corresponding to diameter and vertical line corresponding to spindle speed of cutter, follow nearest curve and use value found in oblique line of figures marked cutting speed.

b To find area of cut: From intersection of horizontal line corresponding to depth of cut and vertical line corresponding to width of cut, follow nearest curve and use value found in oblique line of figures marked area of cut.

c To find cubic inches of metal removed per minute: From intersection of horizontal line corresponding to area of cut and vertical line corresponding to advance of table per minute, follow nearest curve and use value found in oblique line of figures marked cubic inches of metal removed per minute.

To use curve, knowing the diameter of cutter, spindle speed, depth of cut, width of cut, and advance of table per minute, find cutting speed from (*a*), area of cut from (*b*), cubic inches of metal removed per minute from (*c*).

mechanism, the flywheel effect and the speed characteristic of the moto a shaper the power required to reverse is not very great, and is usuall than the power required for cutting.

SLOTTER

195 In most cases the cutting tool is fed inwardly on this type of ma the following example shows how the diagram is used to determine the r removing metal. With other methods of feeding the tool the diagram is in the same way as in the case of a planer or a shaper.

Example:	Width of tool and cut	= 0.5
	Feed per stroke	= 0.06
	Cutting speed	= 35 ft. per min.
	Area of cut 0.5×0.06	= 0.03 sq. in.

196 The cubic inches of metal removed per minute, from the intersect the horizontal and vertical line through 0.03 sq. in. and 35 ft. per min., In the case of mild steel the horsepower required would be 13×0.6 = 7.

DRILLS

197 The power required in drilling operations can also be expressed as stant times the cubic inches of metal removed per minute. The conditio however, more complicated than in the lathe tool, since the friction of th and the chips on the sides of the hole increase the power requirement drill enters the metal. This is especially true when cast iron is drilled, as have a jamming action. The variable cutting speed at the cutting edge drill, from zero at the center to the peripheral speed of the drill, also ca jamming action and tends to increase the power per cubic inch per minut that required to remove the same amount of metal by means of the lath type. With drills generally employed, the value per horse power per inch of metal removed per minute is about double that required by or lathe tools.

198 Fig. 18 is a diagram with full instructions for determining the inches of metal removed with drills. The constants for determining the required are about double those for lathe tools.

Example:	Size of drill	= 2 in. diameter
	Feed per minute	= 2.5 in.
	Speed of drill	=150 r.p.m.
	Metal drilled: cast iron.	

199 The peripheral or maximum cutting speed of the drill is found as f (Rule *a*, Fig. 18): The horizontal line corresponding to a diameter o intersects the vertical line corresponding to 150 r.p.m. on the curve corre ing to a cutting speed of 77.5 ft. per min. The area of the 2 in. drill (rul 3 sq. in. This area at a feed of 2.5 in. per min. corresponds to removin in. per min. (rule *d*). For cast iron the horsepower per cu. in. per min. is 0.8, twice that for lathe tools, hence the power required to drive the d this case is $0.8 \times 7 = 5.6$ h.p., which agrees closely with an actual test

mild steel the power required is $1.2 \times 7 = 8.4$ h.p. In drilling a hole of this size the friction of the chips does not increase the power materially as the depth of the hole increases, since there is sufficient space for the drill to free itself of chips.

MILLING CUTTERS

200 Fig. 19 is a diagram with full instructions for determining the amount of metal removed per minute by a milling machine.

Example:	Width of cut	= 8 in.
	Depth of cut	= 0.2 in.
	Advance of table per min.	= 5 in.
	Area of cut is 8×0.2	= 0.16 sq. in.

201 To find the cubic inches of metal removed per minute, find on the diagram the intersection of the horizontal line through 0.16 sq. in.. and a vertical line corresponding to a table advance of 5 in. per min. The curve passing through this intersection corresponds to a rate of cutting of 16 cu. in. of metal per min. For machinery steel or mild steel, the power required by a horizontal milling machine of this type is about 1.6 per cu. in. per min., making the total requirement $1.6 \times 16 = 25.6$ h.p. A vertical miller requires about 1 h.p. per cu. in. per min., or 16 h.p. under the foregoing conditions.

202 The power required by milling cutters varies according to their construction, and care should be employed to determine the proper constant for each class of cutters. By means of tests made with the graphic meter on motor-driven tools the proper constant can easily be determined in any given case.

APPENDIX NO. 3 SIZES OF MOTORS RECOMMENDED T DRIVE MACHINE TOOLS

203 Tables 8–17 herewith contain the sizes and speeds of motors usua employed with the average duty indicated for machine tools. The consta speed motors are selected with a view to utilizing speeds as near as possi to those obtainable with 60-cycle induction motors. By this means the sa gear ratios can be employed with either direct current motors or 60 cy induction motors.

204 The average load factor for motors driving lathes is from 10 to 25 %. some special machines, as driving wheel and car wheel lathes, the cuts are heavy, which increases the average load factor to from 30 to 40%.

205 For extension boring mills, 5 h.p. motors are used to move the housi on from 10 ft. to 16 ft. mills, 7½ h.p. for from 14 ft. to 20 ft. mills and 10 h.p. from 16 ft. to 24 ft. mills. The load factor of the driving motor on boring m averages fom 10 to 25 %.

206 The load factor of motor-driven drills is about 40%, when the lar drills applicable thereto are used. If the smaller drills are used the load fac averages 25% and lower.

207 For the average milling operations the load factor averages from 1(25 %. On slab milling machines where large quantities of metal are remo it will average from 30 to 40%.

208 The work on this class of machinery is usually light and much time is quired in making adjustments. Hence the load factor is rarely higher than 2(

209 On planers the load factor averages between 15 and 20%. The mo must be large enough to reverse the bed quickly, yet this peak load occurs such short intervals that it does not increase the average load per cycle v much.

210 The work done on shapers is of a varying character. With light wc the load factor will not exceed from 15 to 20%; with heavy work, the load fac will be as high as 40%.

211 The conditions encountered on slotters are similar to those on shape

TABLE 8 SIZES AND SPEEDS OF MOTORS ON LATHES

ENGINE LATHES

Swing In.	Light Duty h.p.	Light Duty Adjst. Speed	Light Duty Const. Speed r.p.m.	Medium Duty h.p.	Medium Duty Adjst. Speed	Medium Duty Const. Speed r.p.m.	Heavy Duty h.p.	Heavy Duty Adjst. Speed	Heavy Duty Const. Speed r.p.m.
14	2	Ratio	1800	3	Ratio	1800	5	Ratio	1200
16	3	1 : 3	1800	5	1 : 3	1200	5	1 : 3	1200
18-20	3		1800	5		1200	7 : 5		1200
22-24	5		1200	7 : 5		1200	10		1200
27-30	7½		1200	10		1200	15		1200
36-42	7½		1200	10		1200	20		900

SPECIAL LATHES

Type	h.p.	Adjustable Speed
Car wheel 48 in.	20	1 : 3
Double axle, moderate duty	15	1 : 3
Heavy duty	25	1 : 3

DRIVING WHEEL LATHES

Size, in.	h.p.	Adjustable Speed
51	15	Ratio 1 : 3
60–69	20	
70	25	1200 r.p.m.
84	25	
90	30	
100	50 5 tail stock	

TABLE 9 SIZES AND SPEEDS OF MOTORS

VERTICAL BORING MILLS

Size, in.	h.p.	Adjustable Speed	Constant Spe
24–30 in.	5	Ratio 1 : 3	1200
36–42 in.	7½		1200
60–90 in.	10 5 -rail		1200
100 in.	15 5 -rail		1200
10 ft.	20 7½-rail		900
12 ft.	20 7½-rail		900
14 ft.	25 7½-rail		900
16 ft.	30 10 -rail		900

TABLE 10 SIZES AND SPEEDS OF MOTORS ON DRILLS

RADIAL DRILLS

Size, ft.	h.p.	Adjustable speed	Constant Spe
4	3	Ratio 1 : 3	1800
5	5		1200
6	5		1200
10	7½		1200

UPRIGHT DRILLS

Size, in.	h.p.	Adjustable Speed	Constant Spee r.p.m.
Friction	½	Ratio 1 : 3	1800
15	¾		1800
20–26	1		1800 1200
28–34	2		1800 1200
42–50	3		1800 1200

MULTIPLE-SPINDLE DRILLS

Size, in.	h.p.	Adjustable Speed	Constant Spe
4–2	7½	Ratio 1 : 3	1200
6–2	10		1200
8–2	10		1200

TABLE 11 SIZES AND SPEEDS OF MOTORS ON MILLING MACHINES

HORIZONTAL—PLAIN OR UNIVERSAL

Table Feed In.	Cross Feed In.	Vertical Feed In.	h.p. Mod. Heavy	Adjustable Speed	Constant Speed r.p.m.
24	8	18	3	Ratio 1 : 3	1800
30	10	18	5– 7½		1200
36	12	20	7½–10		1200
50	12	20	10–15		....

VERTICAL MILLING MACHINES

Table Diameter In.	Spindle Diameter In.	h.p.	Adjustable Speed	Constant Speed r.p.m.
28	4	5	Ratio 1 : 3	1200
32	4	7½		1200
40	4½	10		1200
54	5	15		1200
70	6	20		900

SLAB MILLING MACHINES

Width of Table, in.	h.p.	Adjustable Speed	Constant Speed r.p.m.
24-30	10	Ratio 1 : 3	1200
36 &	15		1200
60]	25		900
36 heavy	25		900
42 heavy	50		900

TABLE 12 SIZES AND SPEEDS OF MOTORS

HORIZONTAL BORING, DRILLING AND MILLING MACHINES

Spindle, in.	h.p.	Adjustable Speed	Constant Speed r.p.m.
3½	3	Ratio 1 : 3	1800
4	5		1200
5	7½		1200
6	10		1200
7	15		1200

TABLE 9 SIZES AND SPEEDS OF MOTORS

VERTICAL BORING MILLS

Size, in.	h.p.	Adjustable Speed	Constant Sp
24–30 in.	5	Ratio 1 : 3	1200
36–42 in.	7½		1200
60–90 in.	10		1200
	5 -rail		
100 in.	15		1200
	5 -rail		
10 ft.	20		900
	7½-rail		
12 ft.	20		900
	7½-rail		
14 ft.	25		900
	7½-rail		
16 ft.	30		900
	10 -rail		

TABLE 10 SIZES AND SPEEDS OF MOTORS ON DRILLS

RADIAL DRILLS

Size, ft.	h.p.	Adjustable speed	Constant Sp
4	3	Ratio 1 : 3	1800
5	5		1200
6	5		1200
10	7½		1200

UPRIGHT DRILLS

Size, in.	h.p.	Adjustable Speed	Constant Spe r.p.m.
Friction	½	Ratio 1 : 3	1800
15	¾		1800
20–26	1		1800 1200
28–34	2		1800 1200
42–50	3		1800 1200

MULTIPLE-SPINDLE DRILLS

Size, in.	h.p.	Adjustable Speed	Constant Sp
4–2	7½	Ratio 1 : 3	1200
6–2	10		1200
8–3	10		1200

TABLE 11 SIZES AND SPEEDS OF MOTORS ON MILLING MACHINES

HORIZONTAL—PLAIN OR UNIVERSAL

Table Feed In.	Cross Feed In.	Vertical Feed In.	h.p. Mod. Heavy	Adjustable Speed	Constant Speed r.p.m.
24	8	18	3	Ratio 1 : 3	1800
30	10	18	5– 7½		1200
36	12	20	7½–10		1200
50	12	20	10–15		....

VERTICAL MILLING MACHINES

Table Diameter In.	Spindle Diameter In.	h.p.	Adjustable Speed	Constant Speed r.p.m.
28	4	5	Ratio 1 : 3	1200
32	4	7½		1200
40	4½	10		1200
54	5	15		1200
70	6	20		900

SLAB MILLING MACHINES

Width of Table, in.	h.p.	Adjustable Speed	Constant Speed r.p.m.
24-30	10	Ratio 1 : 3	1200
36 [illegible]	15		1200
60 [illegible]	25		900
36 heavy	25		900
42 heavy	50		900

TABLE 12 SIZES AND SPEEDS OF MOTORS

HORIZONTAL BORING, DRILLING AND MILLING MACHINES

Spindle, in.	h.p.	Adjustable Speed	Constant Speed r.p.m.
3½	3	Ratio 1 : 3	1800
4	5		1200
5	7½		1200
6	10		1200
7	15		1200

TABLE 13 SIZES AND SPEEDS OF MOTORS ON PLANERS

Medium Duty			Heavy Duty		
Size, in.	h.p.	Constant Speed r.p.m.	Size, in.	h.p.	Constant Spee r.p.m.
24 x 24	5	900	24 x 24	7½	900
30 x 30	7½	900	42 x 42	25	900
36 x 36	10	900	56 x 56	25	900
48 x 48	15	900	Frog and	30	900
56 x 56	15	900	Switch Forge	...	...
			12 x 10 ft.	60	720
			14 x 12 ft.	10 (rail)	...
				75	...
				12 (rail)	720

TABLE 14 SIZES AND SPEED OF MOTORS ON SHAPERS

Size In.	h. p.	Adjustable Speed	Constant Speed r. p. m.
14–20	3	Ratio 1:3	1800
24	5		1200
36	7½		1200

TABLE 15 SIZE AND SPEEDS OF MOTORS ON CRANK SLOTTERS

Light, Medium and Heavy

Size In.	Horsepower		Adjustable Speed	Constant Speed r. p. m.
	Light	Medium		
10	3	5	Ratio 1:3	1800
10–16	5	7½		1200
20	7½	10		1200
26–30	15	..		1200
Geared Slotters				
24–60	20	....	1:3	900

TABLE 16 SIZES AND SPEEDS OF MOTORS ON COLD SAWS

Diameter In	Thickness In.	h. p.	Adjustable Speed	Constant Speed r. p. m.
12	3/32	2	Ratio 1:3	1800
15	3/32	2		1800
18	1 3/64	3		1800
20	1 3/64	3		1800
24	1 3/64	5		1200
32	1 3/64	7½		1200
36	1 3/64	10		1200

TABLE 17 SIZES AND SPEEDS OF MOTORS ON GRINDERS

Size In.	h. p. Medium	h. p. Heavy	Constant Speed r. p. m.
10x 50	5	7½	1200
10x 72	5	7½	1200
10x 96	5	7½	1200
10x120	5	7½	1200
14x 72	10	..	1200
18x120	10	15	1200
18x144	10	15	1200
18x168	10	15	1200
18x 96	10	15	1200
44-in car wheel grinder		30	900

APPENDIX NO. 4 OVERHEAD CHARGES AND MACHINE-HOUR RATES

212 The following analysis outlines a method of determining the hourly head charges per machine tool, which will be called the *machine-hour* Overhead charges can be grouped in three main classes:

A Charges against the entire factory.

a Fixed charges: these include interest and depreciation, and insurance on buildings, grounds and accessories.

TABLE 18 MACHINE HOUR RATES

Type of Machine	Charges per Hour				Depreciation	Power	
	Fixed	Variable	Salaries	Interest			
Vertical Boring Mills.							
40-in.-60 in.	$0.02	$0.25	$0.15	$0.05	$0.05	$0.01	$
72 in.-100 in.	0.04	0.45	0.25	0.08	0.08	0.01	
10 ft.-14 ft.	0.05	0.80	0.40	0.15	0.15	0.02	
16 ft.-24 ft. Ext.	0.08	2.00	1.00	0.30	0.30	0.03	
Average per cent of total	3%	52%	28%	8%	8%	1%	
Radial drills, 5 ft	$0.02	$0.30	$0.20	$0.03	$0.03	$0.01	$
Radial drills, 10 ft.	0.04	0.60	0.35	0.09	0.09	0.01	
Average per cent of total	3%	51%	31%	7%	7%	1%	
Engine Lathes:							
30 in.-40 in.	$0.02	$0.25	$0.12	$0.04	$0.04	$0.01	$
40 in.-60 in.	0.03	0.50	0.25	0.10	0.10	0.01	
Average per cent of total	3%	51%	25%	10%	10%	1%	
Planers:							
36 in.-56 in.	$0.04	$0.55	$0.30	$0.05	$0.05	$0.01	$
7 ft.-10 ft.	0.06	1.10	0.60	0.15	0.15	0.02	
12 ft.-14 ft.	0.15	2.60	1.40	0.25	0.25	0.03	
Average per cent of total	3%	55%	30%	5.5%	5.5%	1%	

b Variable charges: these include repairs and renewals on bui and accessories, omitting all charges which can be set off di to a particular section of the factory; charges against the room and the tool room; defective design, material or worl ship; printing and stationery; lubricants and general mai turing supplies.

c Salaries (not chargeable to a definite section): these include cost of superintendence (manager, superintendent, foreman); engineering and drawing; clerical force, including office boys and general laborers.

B Charges against each section of the factory.

a Fixed charges; including an equitable portion of the total factory fixed charge and interest, and depreciation on auxiliary apparatus located in the section (except machine tools).

b Variable charges: these include a portion of the variable charges as well as similar charges belonging to the section, such as repairs and renewals, storeroom and tool room charges, defective design, material and workmanship, lubricants and manufacturing supples.

c Salaries: including a portion of the total salaries as well as those belonging exclusively to the section, that is, foremen, clerks, errand boys, laborers, cranemen, etc.

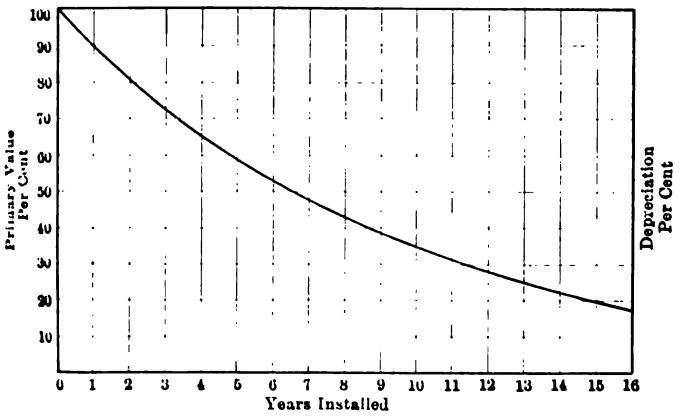


FIG. 20 DEPRECIATION AT 10% REDUCING BALANCE

C Charges against each machine tool.

a Portion of fixed charge.

b Portion of variable charge.

c Portion of salaries charge.

d Interest on cost of tool, fairly taken at 6%.

e Depreciation of value of tool (see Par. 213–215).

f Cost of power to operate tool, including also lighting and crane service.

DEPRECIATION OF VALUE OF MACHINE TOOLS

213 A method frequently used in calculating the depreciation in value machine tool is to allow 10% of a reducing balance; that is, 10% of the first if charged off the first year, 10% of the remaining cost, the second y and 10% of the second remainder the third year, etc. This method is b upon the fact that the apparatus actually decreases in value year by y Allowance for depreciation in any given year can be made easily by aid of the curve in Fig. 20. This curve gives the percentage of the first corresponding each year to 10% on the reduced balance. For example, curve shows that the depreciation on a tool that has been in service years will be 6. 6% of the original cost. If this cost was $4500, the allowanc depreciation during the sixth year according to the 10% reducing balance me is $4500 × 0.066 = $297. Since this is 10% of the reduced cost, the valu the tool at the end of the fifth year is $2970.

214 Tools designed for special work will be discontinued after a comp tively limited period, and therefore, depreciate in value much more rap than is indicated by the foregoing method: a special allowance frequently n for such tools is generally known as *utility depreciation.*

215 Table 18 contains a summary of machine hour rates obtained by method. It is assumed that machines have been installed six years, so the depreciation is 6% on a basis of 10% reducing balance.

No. 1276c

MECHANICAL FEATURES OF ELECTRIC DRIVING IN MACHINE SHOPS

By John Riddell, Schenectady, N. Y.

Member of the Society

216 It is with the mechanical features of motor driving that this paper is to deal, and chiefly with what has been done in the electrical equipment of the most commonly used machine tools in the plant of the General Electric Company, at Schenectady, with a few sketches of some large work that has been erected outside.

217 Some ten or twelve years ago it was decided to erect a large and up-to-date electrically driven machine shop, and plans for the electrical equipment were started some time ahead of the completion of the building. At first the plan was to have every machine tool individually driven, but the time was so short that we abandoned this idea and concluded to arrange the machines in groups, each driven by a motor direct-coupled to the end of a section of lineshaft. This arrangement was used only to take care of small and medium-sized machines, of which few, if any, were at that time equipped with individual motors.

218 Considerable difficulty was experienced in arranging the lineshafts and countershafts in this system, owing to their being traversed by small side-bay electric cranes. Fig. 21 gives a general idea of this method of group-driving. However crude it may appear in the light of present practice, it was considered in its time thoroughly up-to-date.

219 One of the mechanical difficulties encountered in attaching individual motors to small machines was the unwieldy size of some of the earlier motors of small capacity. Sometimes the motor would be as large as the machine, or larger, and this feature was largely responsible for the prevalence of group-driving of small machines, even where the individual drive would have been preferred. Recent improvement in motor design has led to a great reduction in the size of motors for a given capacity, so that the 25-h.p. motor of today is not nearly so

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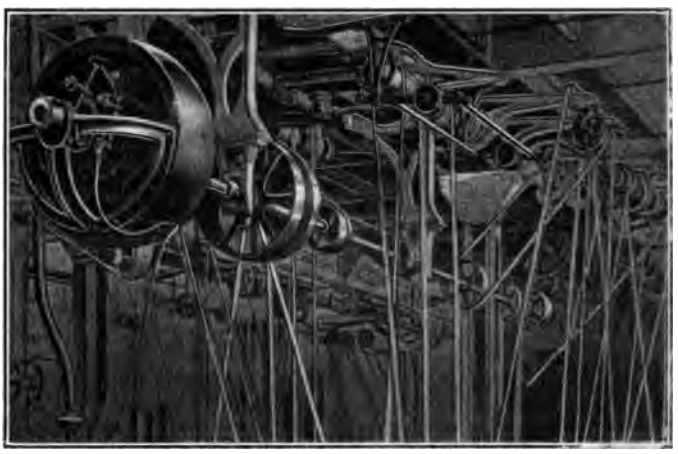


FIG. 21 METHOD OF GROUP-DRIVING

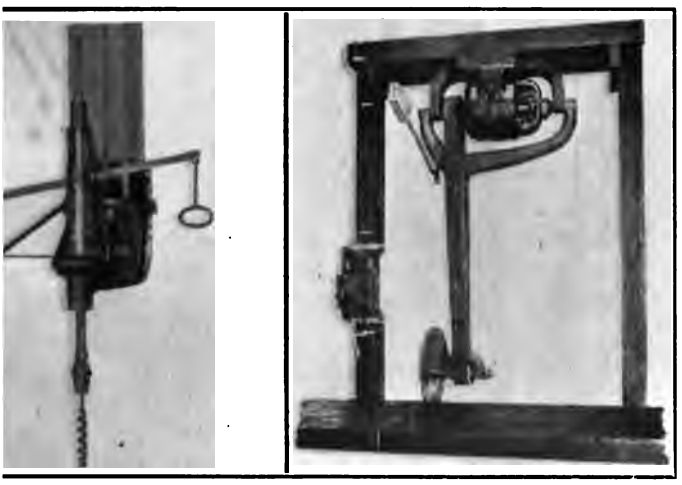
large as the 10-h.p. motor of earlier years. It is therefore much ea now to make the motor an integral part of the machine; and even wh only fractional parts of a horsepower are required, for light operatic

FIG. 22 LATHE DRIVEN BY INDUCTION MOTOR CONCEALED IN CABINET LE

motors of very small weight and well adapted in size to the tools are now available.

SMALL MACHINE TOOLS

Figs. 22, 23 and 24 show good examples of individual motor which the motors are inconspicuous and form integral parts machine tools. Fig. 22 shows a lathe driven by an induction concealed in the cabinet leg. Fig. 23 illustrates a wood-boring driven by an induction motor through a single pair of bevel e inverted motor is bolted to a plate, which is in turn bolted



Wood-Boring Machine n by Induction Motor ge Single Pair of Bevel Gears

Fig. 24 24-in. Reliance Swing Saw with Motor

tom of a post and to the frame of the tool. At first the plate ged to swivel on the tool post, in order to provide means for ne tool longitudinally over the work; but later this adjust- abandoned, as it proved to be easier to move the work hori- vith reference to the tool. This tool is a good example of the ess of the electric motor, and its easy adaptability to wood- achinery. Fig. 24 shows the application of a direct-current a 24-in. swing saw.

LARGE MACHINE TOOLS

221 The large lathes, vertical boring mills, planers, milling machines etc., were supplied each with its own individual motor, which was a marked improvement over the original belt-and-countershaft method of driving. Since starting this work, the company has changed over several thousand machine tools to motor drives. Most of the difficulties in changing from belt to motor driving were in making suitable

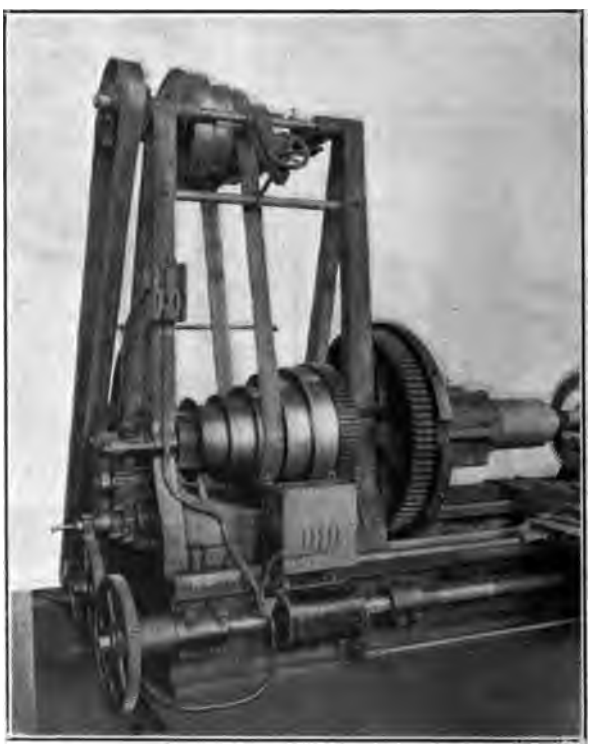
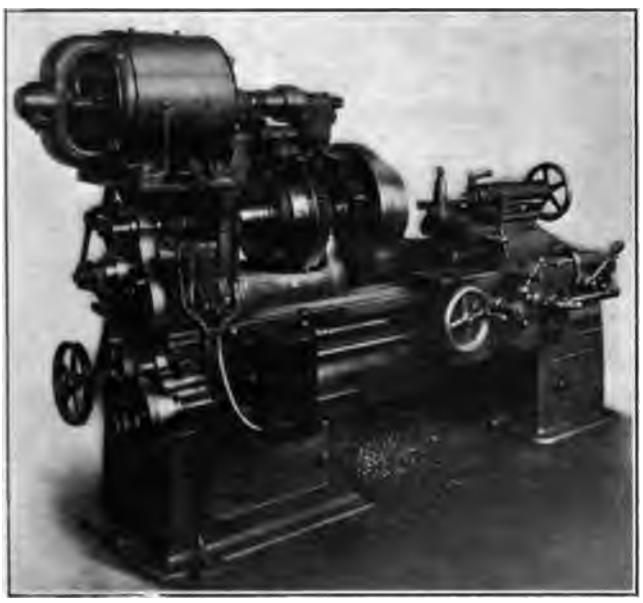


FIG. 25 42-IN. BEMENT-MILES LATHE DRIVEN BY CONSTANT-SPEED MOTOR USING CONES AND BELTS

connections between the motor and the tool to be driven. We do not pretend that in every case we have adopted the best arrangement, as in many cases the machine tool is not of sufficient value to warrant the expensive mechanical connection.

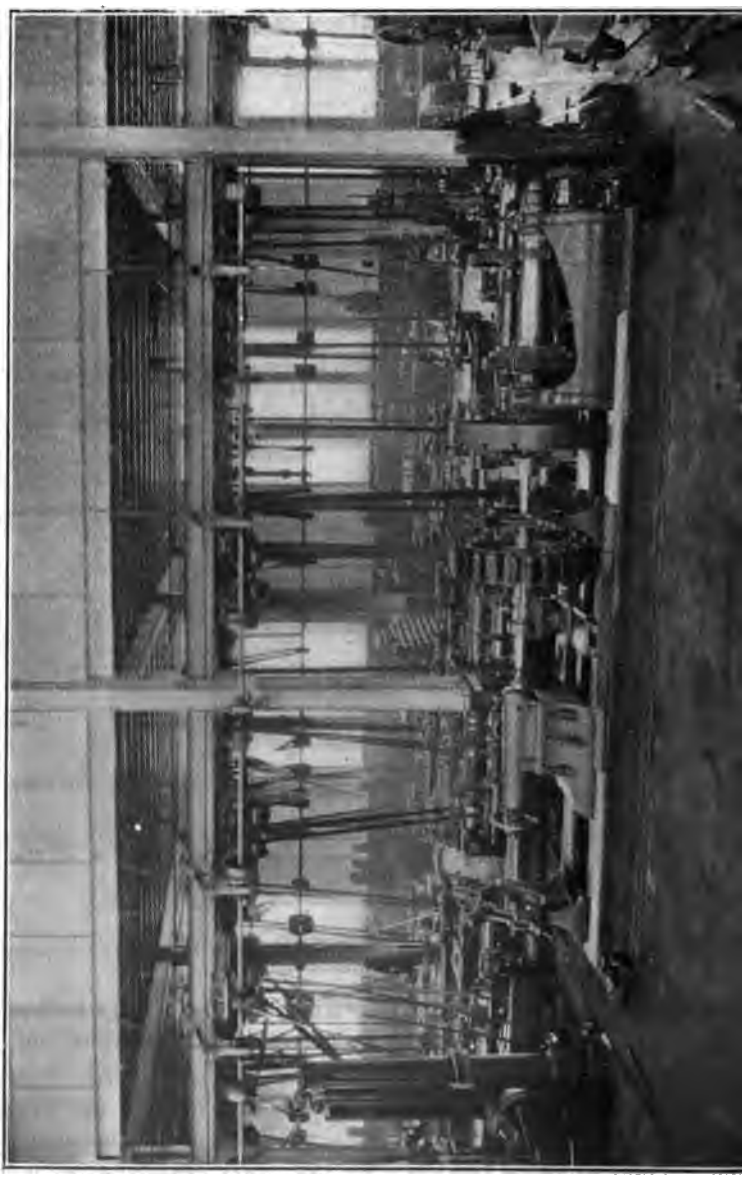
2 Take, for example, a medium-sized lathe of relatively moder-
alue. If an expensive transmission device was required in order
ply a motor to the lathe, the total cost of the lathe, as changed,
it easily be more than the price of a new lathe especially designed
notor driving. In such cases it is found expedient to erect the
tershaft and cone about four feet above the headstock, on suitable
kets, fasten the motor in a convenient place on the machine, and
inue the use of cones and belts. Such an arrangement is shown in
25.

3 In all cases where old machine tools are converted to electric
ing, it is desirable to mount the motor on some part of the machine



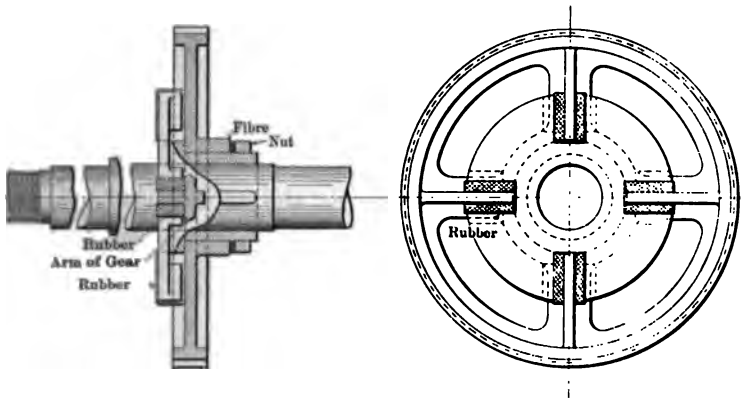
26 24-IN. FITCHBURG LATHE DRIVEN BY MOTOR, WITH REVERSING GEARS

ossible, rather than on the floor near the machine. In the former
e, the machine tool constitutes an independent self-contained unit
ch can be moved by the crane as a whole and located wherever
ired. Cleanliness is promoted, by leaving a clear floor space to
ep, and the motor is less liable to accumulations of dirt caused by
eping. There is also a tendency for the motor and the machine
l to become shifted out of alignment, if they are separately mounted
the floor.



224 For lathes of more importance, and where the value of the tool arrants, we make an all-gear drive, with reversing gears, which are sed principally for screw cutting. Fig. 26 shows a lathe equipped with :versing gears. More recently we have produced motors which can e very quickly reversed, obviating the necessity of reversing-gears.

225 When the original change was made from belt to motor drive iere was one particular triple-geared lathe, 72-in. swing, to which we pplied a two-to-one variable-speed motor. The only change neces- ary in this case was to substitute two gears for the lathe cone, mount- l on a quill, and made to engage with a pair of rocking gears on the iotor. This gave a speed variation of four to one at the motor, and ith the triple gears of the lathe, we had an exceedingly fine speed ange. This lathe is shown in the foreground of Fig. 27. The motor is



IG 28 DIAGRAM OF DEVICE TO OBVIATE CHATTER MARKS ON FINISHED WORK

laced in a most advantageous position, in the headstock under- neath the spindle. During about ten years' service it has never been removed.

226 In a shafting department like that of the General Electric Com- pany, where the range of size does not vary over three or four inches on the standard work, no very great speed changes are necessary, and a two-to-one motor usually has range enough to meet all requirements. What is particularly needed is ample power, strength of parts, and sim- plicity of construction, especially in lathes used for roughing, which are usually handled by unskilled labor.

227 For finishing shafts, however, where greater accuracy is re- quired, an all-gear drive with steel gears is not satisfactory, because the chattering set up by the action of the gear teeth is very apt to be trans-

mitted to the finished work, leaving parallel ridges. This difficulty was overcome in some special lathes which we had built for the purpose, in which the driving gear on the main spindle was left loose and acted on the driving plate, keyed to the spindle, through four rubber buffers. This device is shown in Fig. 28.

228 More recently, trouble from this same cause was experienced in one of our tool departments, and was corrected by the use of a pinion made of muslin. This pinion has several features which especially adapt it to motor-driven machine tools. It is practically noiseless and very durable, does not shrink, and is sufficiently flexible and elastic to absorb vibrations which might be transmitted to the finished work.

229 Another application to motor driving in connection with lathes, and one that has been much appreciated, is the use of an auxiliary motor to operate lathe carriages having a long travel, about 35 ft. The motor is bolted to one side of the carriage, and carries a pinion which meshes with the hand-wheel gear. A two-way switch is provided for operating the motor in either direction. The use of a motor not only saves the operator a difficult task, but it has also proved a great economy of time. It formerly required 30 to 35 minutes to shift the carriage through its full travel, and the hand wheels were placed so low that a man had to stoop to use them. The motor will move the carriage from one end of the lathe to the other in a minute and a half, and it can be stopped at any point within 1/16 in. of the cut.

230 The best location for a motor on a lathe, and on most machine tools, is as low down on the machine as possible. The amplitude of the vibrations set up will be smaller, the closer the motor is to the floor, and the liability of chattering will therefore be reduced. The location of the motor in the cabinet leg or in the headstock of a lathe, as shown in Fig. 22 and Fig. 27, is ideal, but there are, of course, many cases where the motor must be mounted over the headstock because no other place is available. The necessity of having the motor out of the way of the work is obvious, as turnings of chips, if allowed to get into the motor, would at once give rise to electrical troubles, especially in direct-current machines.

CONTROLLERS

231 The location and arrangement of controllers for lathes depend upon the class of work to be performed. Where the lathe is started, stopped, and varied in speed by the controller, the latter should be mounted on the front of the lathe, and the handle extended by means

of a shaft to the lathe carriage, where it will be constantly under the hand of the operator. Ease of control unquestionably results in the rapid and economical production of work. Where the work varies considerably in diameter, frequent changes of speed will be required, and where the most efficient cutting speed can be obtained simply by turning a conveniently located handle, the work will be turned out at a maximum speed. If frequent shifting of belts is required, a great

FIG. 29 EVOLUTION OF APPLICATION OF MOTORS TO PLANERS
LINE SHAFT DISCARDED, COUNTERSHAFT DRIVEN FROM MOTOR ON FLOOR

deal of the work will be done at less than maximum speed, owing to the extra exertion involved.

232 For lathes with constant-speed motors, operated with clutches and shifting levers, or machines on which continuous automatic operations are carried on, such as screw machines, the motor can be kept running for long periods without attention from the operator. In such cases the controller may be mounted at any convenient place on the machine, or near by on the floor, by means of a bracket.

PLANERS

233 Figs. 29, 30 and 31 illustrate the evolution of the application of motors to driving planers at the Schenectady shops. The first step, as shown in Fig. 29, was simply to discard the lineshaft and drive the countershaft from a motor placed on the floor. When this planer was operated by belts it was next to impossible to reverse it in a shorter space than about thirty inches, and even then with a great deal of wear and tear on the belts. Early in 1900 the company produced its first magnetic clutches for driving planers. The first of these clutches was applied to a Bement-Miles planer, 30 ft. wide by 20 ft. long. With this clutch, Fig. 30, we are able to reverse the planer prac-

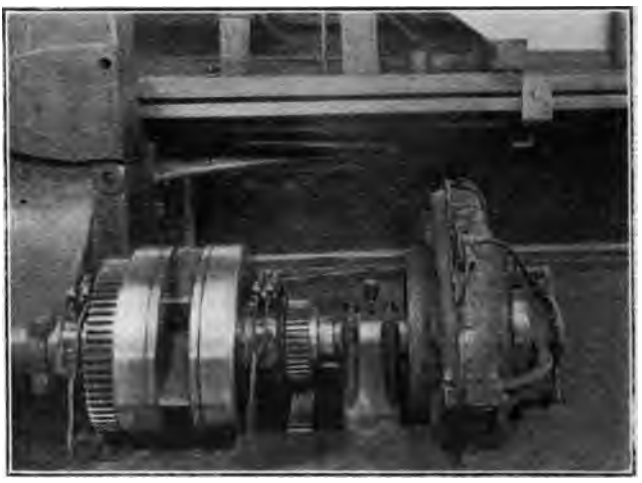


FIG. 30 EVOLUTION OF APPLICATION OF MOTORS TO PLANERS
MAGNETIC CLUTCH

tically to a line, and to reduce the space required for reversing to about 12 inches. Some trouble was experienced, however, with these first magnetic clutches, owing to the design of the magnets, and pneumatic clutches of a peculiar design were subsequently adopted and have been entirely satisfactory. Fig. 31 shows the arrangement of the motor and pneumatic clutch, as applied to the planer.

234 Our second lot of magnetic clutches was redesigned to eliminate the difficulties experienced with the first lot, and the new ones were applied to a number of portable slotters. These machines have been in continuous operation practically night and day up to the present

time. The clutches have operated with entire success, and I believe the magnetic clutch will eventually be found an important and efficient feature of transmission gears for planers and slotters.

VERTICAL BORING MILLS

235. In our original scheme for attaching motors direct to boring mills, an all-gear drive, with variable-speed motors, was selected, and with very slight changes, has been employed up to the present time. Fig. 32 shows a number of boring mills equipped in this way; the motors

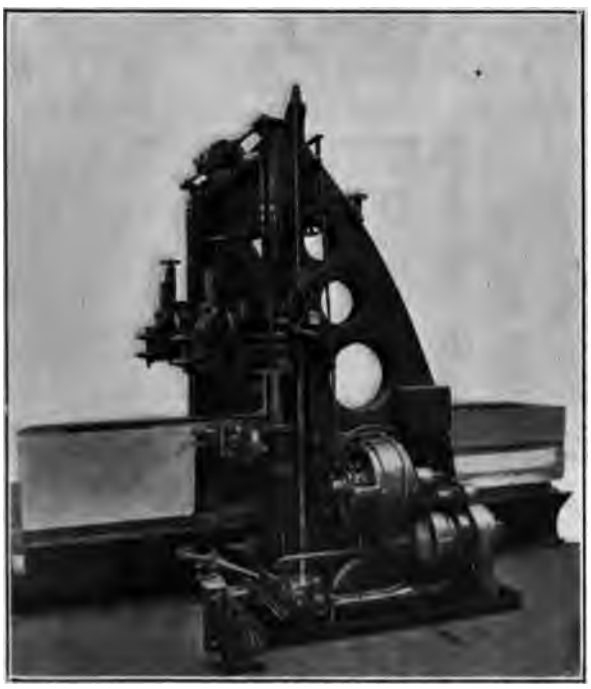


FIG. 31 EVOLUTION OF APPLICATION OF MOTORS TO PLANERS

COMPRESSED-AIR CLUTCH, TWO CONES

not being visible in the illustration because they are placed below the floor level between the side frames back of the revolving table. A solid foundation is laid, extending under the entire machine, a depression in the back between the side frames forming a bed for the motor, which is securely fixed in position. This common foundation makes the motor and the machine a single compact unit, and no additional

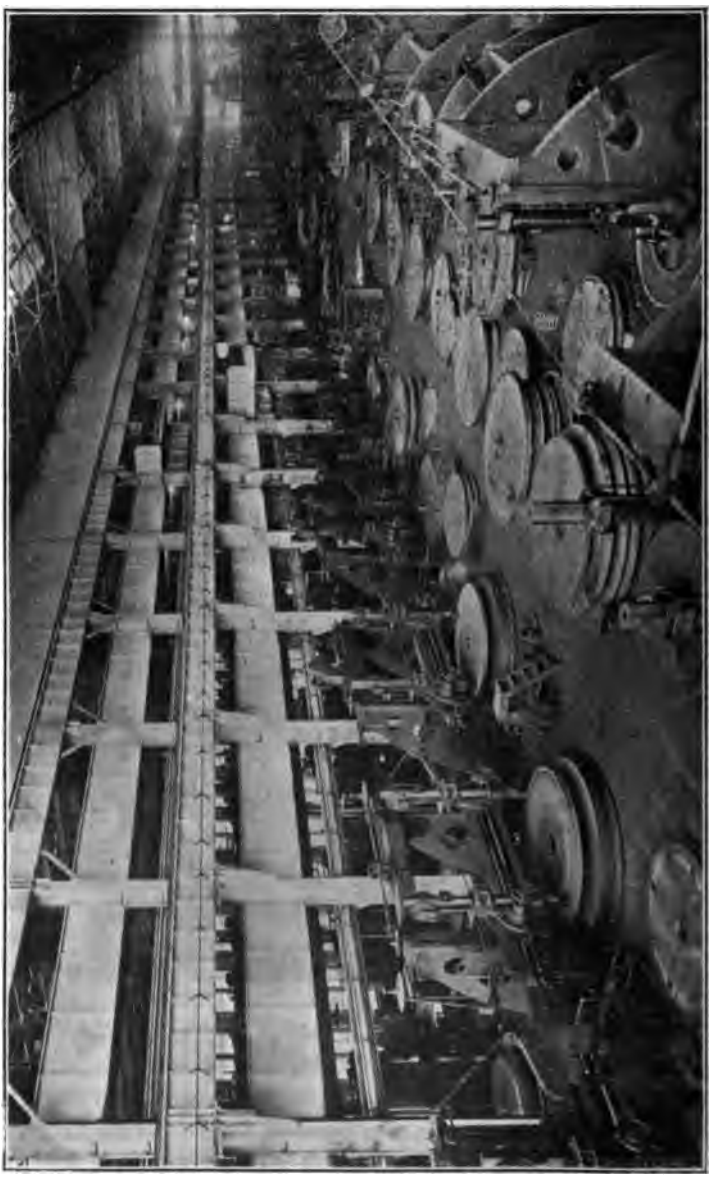


FIG. 32 BORING MILLS EQUIPPED WITH VARIABLE-SPEED MOTORS, ALL-GEAR DRIVE

space is required for the motor. No work put upon the table can fere with the motor, the gears are entirely out of sight, and the con-er is placed at the right-hand side of the machine, where the ator usually stands.

6 On boring mills from 20 ft. to 25 ft. in diameter, with the l slow intermediate and direct-gear drive that comes with the mill, riable-speed motor of two-to-one ratio gives a very satisfactory d range.

33 Application of Motor to Machine Tools on Iron Floor Plate

PORTABLE TOOLS

7 Various machine tools of the portable type are used in ordi-large machine shops, and are placed in various positions on iron plates. The efficiency of these machines, such as the rotary ers, slotters, etc., used in erecting departments, has been greatly eased by the use of electric motors. A group of these tools is wn in Fig. 33, working on a large casting. The use of portable s was almost impossible before the advent of the electric motor, now the machine tools used in erecting shops, and in isolated es away from the source of power, when equipped with electric ors are ready to run at a moment's notice. On up-to-date rotary ers the motor is placed on the carriage, the under-side of the bases laned, and means are provided for transferring the planers by elec-cranes.

238 Under the old arrangement, if machinery stood idle for days and weeks, the countershafts and loose pulleys were so neglected that they would squeak; some one would then throw off the belts to stop the noise, and two hours' work was frequently necessary before they could be started for a hurried job. The same thing is true of some boiler makers' and blacksmiths' machines, such as rolls, shears, cutting-off machines, etc.

BELTING

239 Twenty-five or thirty years ago, in the days of the old jobbing shop, the buildings were not so high-studded, and the lineshafts and countershafts were usually within reach of a twelve-foot or fifteen-foot ladder at the most. Cone belts running to machine tools were very easily manipulated, and an expert lathe hand would never think of using a pole for shifting his belt from one step of the cone to another. But in these days of sanitary buildings, with ceilings from twenty to twenty-five feet high, it becomes an exceedingly difficult problem to arrange countershafts within reasonable heights; to say nothing of the necessary length of the vertical belts, the dust set in motion, and the difficulty of painting and whitewashing ceilings for the sake of cleanliness.

240 Another condition of lineshaft driving which has not been much spoken of, of late, is the difficulty of keeping the shaft in alignment, where the hangers are suspended from the roof trusses. The writer has seen such shafts five or six inches out of alignment, due to a heavy fall of snow on the roof, or to the settling of foundations. Another trouble is that due to state laws and shop rulings, where a few trained men are employed as belt-lacers and it is against the rules for men who are not belt-lacers to do the work. This is the cause of numerous delays, with consequent loss of production.

241 The only advantages that may be claimed for belts is that they take up the vibration of the gears, and thus prevent chatter marks on fine work; and that they will slip under over-load and be thrown off the pulley, stalling the machine, instead of breaking the tool or spoiling the work. It has already been explained how the effect of vibration has been remedied by means of rubber buffers or muslin pinions, and there are exceedingly few cases where belt-slip is not a detriment rather than an advantage. The use of high-speed tools calls for a considerable increase in the power necessary to drive the machines, as these tools take a heavier cut at a higher speed than those of car-

bon steel. These conditions make belt-slip very objectionable, and one of the chief advantages of motor driving is that it increases the power of machine tools beyond the capacity of belts of reasonable length. Modern practice is in the direction of eliminating the belt almost entirely, although there are a few machine tools, such as the older types of automatic-screw machines, grinding machines and some wood-working machines, on which they are necessarily retained.

FIG. 34 RAIL MILL DRIVEN BY 6000-H. P. INDUCTION MOTOR, SHOWING BREAKABLE BEARING; INDIANA STEEL COMPANY, GARY, IND.

242 The great majority of metal-working machines are best adapted to motor driving through all-gear connections, although a few machines, such as small grinders, buffing wheels, polishing wheels, etc., are best connected direct to the motor shaft.

STEEL MILL WORK

243 The application of motors to metal-forming machines, such as rolls for rolling steel, charging cranes, etc., does not belong strictly to machine-shop practice, but the work of these machines is closely allied to what is required of other metal-working machines. Some of this work now performed by motors is the heaviest kind of mechanical work ever attempted by any kind of prime mover. Fig. 34 shows a large induction motor driving an up-to-date steel rail mill, requiring 6000 h.p. or more. The operation of an entire mill is fre-

quently dependent on the continuity of operation of each piece of apparatus. For this reason it has been the practice to build the steam engines which drive mill machinery of the most substantial material and design. In replacing engines by electric motors, these same features were embodied in the motors.

244 The breakable coupling between the engine and the rolls is retained when motors are used. This coupling is of such strength that it breaks before the rolls are injured by shocks. The coupling frequently breaks diagonally, and a very heavy end-thrust is sometimes

FIG. 35 MILL MOTOR USED ON CHARGING CRANE, BLOOMING MILL, ILLINOIS STEEL COMPANY, SOUTH CHICAGO, ILL.

produced, tending to separate the ends of the coupling. With the engine drive, this end-thrust frequently slides the roll housings out of their places, and considerable time is required to replace them. When motors are used, this difficulty is readily avoided by allowing the shaft of the motor to slide longitudinally in its bearings. To keep the motor shaft in its proper position, a breakable end-thrust bearing has been devised, which allows a bolt to break at a predetermined pressure before any other part of the machinery can be injured. This breakable bearing is shown in Fig. 34. It acts through the breakage of the long bolts shown alongside of the bearing housing.

The ready replacement of the parts when the coupling breaks is only one of the advantages incidental to the use of the motor for driving rolls.

245 Another style of motor, known as the mill motor, is illustrated in Fig. 35 and Fig. 36. It is used on slab-charging cranes, screw-downs, mill tables, etc., where it is subject to very rough handling, intense heat, severe over-loads, dirty surroundings, and other unfavorable conditions. All portions of these motors, such as the frame, shaft and bearings, are built unusually heavy to withstand safely the shocks to which they are subject.

246 There are thousands of other motor applications, which the writer will not attempt to describe. In Mr. DeLeeuw's paper are enumerated some of the important points in regard to applying motors

FIG. 36 TWO 50-H.P. DIRECT CURRENT MOTORS

to machine tools. The writer has therefore endeavored to confine himself to a consideration of those mechanical features not already covered.

247 At the Schenectady plant alone we have running some 8500 machine tools, of which 8150 are individually motor-driven. Group-driving has been adopted for some sensitive drills, speed lathes, and other small miscellaneous machines. Of the above tools there are 48 portable machines, consisting of slotters, milling and drilling machines, radial drills, etc. These machines are operated on 32,675 sq. ft. of iron floor plate, in addition to which there are 7000 sq. ft. of iron rails. cemented into the floor, for erecting purposes.

248 Had we continued our extensions since 1899, using lineshafts, countershafts and belting, we would have approximately 34,570 ft. of lineshaft, or about 6½ miles, and about 4¾ miles of countershaft, which would require about 21,225 hangers and bearings. Allowing two belts to each machine, with an average length of 25 ft. per belt, we would have for the 8500 machines a total of 425,000 ft. of belting, equal to about 80½ miles.

No. 1276*d*

DISCUSSION ON ELECTRIC DRIVING IN MACHINE SHOPS

The three preceding papers on Electric Driving were presented at meetings of the Society at St. Louis and New York, April 1910, and the discussions at these meetings follows. At the New York meeting the American Institute of Electrical Engineers coöperated and contributed a paper by Charles Fair, Assoc. A. I. E. E. This paper was published in full in the Proceedings of the American Institute of Electrical Engineers for May 1910. It discusses the advantages of the individual electrical drive for machine tools, with special references to tools which are already in service with belt drive. In such cases it is necessary to consider in choosing a motor the nature of the work, the speed changes required, the number of tools thus to be equipped, and the condition of the tools. Even where a motor is applied to a tool designed for belt drive, the new drive should be simple in construction, satisfactory in operation, and sightly in appearance. Numerous methods of attaching motors to old tools are shown and described.

The choice of control, whether it be with old or new tools, is fully as important as the choice of the motor and it is necessary to consider the accessibility of, the controller to the operator, the method of attaching it to the tools, and its position relative to other tools. Accessibility in case of accident is an important consideration and the starting compensator should be placed where the motor or some of the moving parts can be seen by the operator. Wherever possible, both controller and motor should be attached directly to the tool. In the case of portable tools this is an absolute necessity. The effect of convenient control upon the output of the tool is emphasized and various types of controllers and methods of application are shown and described.

A table is attached which is designed to aid in a general way in the choice of motors, and numerous methods used to maintain standard motor shafts are illustrated.

DISCUSSION AT ST. LOUIS

W. F. M. Goss. A few years ago it was commonly believed that the electric motor could be used only under certain favorable conditions. If there are any today who hold such an opinion, they should visit the great steel works at Gary, Ind., where not only machines but compressors and roll trains are electrically driven, to be convinced that there is nothing in machine driving that can not be done by the electric motor.

A modern machine shop, whether for repairs or manufacture,

presents an equipment of specialized machines. The capitalization which underlies the operation of the shop has been extended enormously in these later days, and the added cost of a motor to drive an individual machine is now more easily met than formerly. If the layout of the shop is properly balanced and if there is business sufficient to keep the machines going, an individual motor for each machine will increase the output and improve the efficiency of the shop.

I do not believe that there are many cases where it will pay to fit motors to old machines. There may be individual cases where this may profitably be done, but the new motor and the old machine will always be less efficient than a complete new outfit. If a point is reached in the development of a shop where electrification is in order, it will generally pay to provide new machines which will be up to the standard of the motor.

I am convinced that the machine tool of the future is to be an individual motor-driven machine, a machine in which we shall not see pulleys, belts, or gears. Such a machine will not only be powerful, ready for instant service and easy to maintain, but it may be taken from its station if desired and moved to its work. It will be an instrument which, because of these facts, can be used in the development of a much larger output than will ever be possible from machines of the ordinary characteristics.

E. R. FISH.[1] There are probably few manufacturing plants designed at present which do not provide in a greater or less degree for electric transmission of power. In many instances provision is made for a generating plant, but sometimes it is more economical to purchase current from a central station. My own experience has been in connection with a shop for the manufacture of boilers. In plants of this kind several methods of power transmission are required, but a great many of the tools can best be driven by motors. In fact the use of motors permits the only rational layout of a shop of this sort for economical production. Any other form of motive power can be used only at great inconvenience, with poor economy, and with large maintenance charges. With motor drives the machines can be located exactly where they are wanted and where the successive operations will progress without unnecessary handling or delay. We use the 220-volt, 3-phase, 60-cycle current and have found it entirely satisfactory. It drives plate-working tools of all sorts through individual

[1] Secretary, Heine Safety Boiler Co., St. Louis, Mo.

motors, drives a small machine shop through a lineshaft, and operates a 25-ton traveling crane. In our case it was quite impracticable to use power from a public-service station because our processes required a power house of our own. We did want an emergency connection from the outside in order to provide against possible failures of our own generator but the ready-to-serve charge was quite prohibitive. A large portion of our work is done by hydraulic and pneumatic tools, so that even though the generator should fail, the works would not be entirely shut down. It was therefore unnecessary that this charge be incurred. It is undoubtedly true that in many instances a protection against break-downs which would completely close the plant would justify the cost of such an outside connection.

A. H. TIMMERMAN.[1] The choice of direct or alternating current for machine shop drives depends largely upon whether there is a possibility of throwing over to a power company's circuit. If the ready-to-serve charge is not too great, the alternating-current distribution is by far the best, because in case of failure of supply the alternating current of the power company can be relied upon.

In the case of an individual installation in which the amount of power required is large and there is no public service corporation to rely upon, the question of direct or alternating current is largely a question of the area covered by the plant. Alternating current is satisfactory for both small and large plants; but direct current is hardly suitable for a plant extending over a considerable area, because of the large drop in voltage due to the long lines required.

Six or eight years ago a great deal was heard about adjustable-speed motors for all forms of machine-tool drive, but machine tool builders have found it necessary to build their tools so as to get the necessary changes in speed mechanically.

I was rather surprised that emphasis was placed on the squirrel-cage polyphase motor. There is an increasing demand on the part of the power companies for the wound-rotor type. The squirrel-cage draws a very heavy current at starting, in comparison with that used by the wound-rotor type. With the latter type full-load torque is obtained with full-load current, or double torque with double current. The squirrel-cage type requires for full-load torque from two to four times full-load current, depending upon the design of the motor.

In this connection it is also of interest to note that the single-

[1] Superintendent, Wagner Electric Manufacturing Co., St. Louis, Mo.

phase alternating-current motor can be used just as well as the polyphase motor for tool drive. In fact in many installations it is much better because a single-phase motor, starting on the repulsion principle, has an exceedingly high torque and draws very much less current from the line for a given torque, than is drawn by any other type of motor.

The amount of power drawn for any tool varies from one-tenth full load to a load and a half, and the motor on an individual tool must be able to take care of the largest load that the tool is liable to have. On the other hand, if five or ten tools are grouped together, a motor that has perhaps a quarter of the sum of the individual horsepower capacities required on the different tools may be installed. This is shown by the fact that even where a group drive is used, the actual power drawn from the generator is very often not in excess of 40 to 60 per cent of the total horsepower connected to the generator.

In the installation of alternating-current motors care should be taken that motors not too large for the work are chosen. The alternating-current motor has a very much heavier overload capacity than the direct-current type, and since the power factor at fractional loads is rather low, it is better to have alternating-current motors overloaded than underloaded.

P. A. MORSE.[1] If it is necessary to use alternating current from the source of power it is very frequently advisable to put in motor-generators, to take care of machine tools or of hoist motors in such a way that a much better power factor is obtained, thereby decreasing the watt load and increasing the capacity of the generating units. The Grand Trunk shops have some large motor-driven compressors to which are coupled synchronous motors. At a plant in St. Louis in which the power factor was very low, the slip-ring type of alternating-current motors was used for certain work. When these were changed recently to direct-current, it increased the power factor and the capacity of the generating plant.

While alternating-current motors, both single-phase and polyphase, have in recent years been adopted very widely as sources of power in the machine shop, the fact still remains that with a class of work which calls for mechanically different sizes of material to be passed through, and where the processes on a given machine tool

[1] Engineer, Western Electric Co., St. Louis, Mo.

are not the same from day to day, it will be almost imperative to use the direct-current motor.

Recent practice is to furnish direct-current motors with inter-poles to improve the commutation and the advantage claimed for the alternating-current motor, that it gives less trouble, should not be as much of a factor hereafter.

The alternating-current motor, of course, has practically only the bearings to be looked after, but the narrow air-gap, which is necessary in order to correct certain other things which would make the motor undesirable, must be balanced against commutator trouble. Within the last few years considerable work has been done in bettering the commutation of motors. This fact has not been generally recognized but will have its bearing on future installations.

H. H. HUMPHREY.[1] In connection with stand-by service from a public utility company, it is often an advantage to be able to start part of the plant before the power plant is ready. I know of one case where the entire plant ran for about three months on central station power. This service has been abandoned this year because it was found that the isolated plant is much more reliable than the central station service in this particular case.

A growing industrial plant is generally provided with reserve power capacity, while on the other hand the central station companies are generally overloaded. If they are not this year, they will be next, for the reason that they connect more customers than their total capacity.

O. STEPHENSEN.[2] Regarding the relative merits of direct and alternating-current motors, there are many cases in which a constant-speed motor can be used, especially for quantity manufacture. Only where the work changes from one job to the next or from moment to moment is an adjustable-speed motor required.

I also take issue with the objection made to the alternating-current motor because of the small air gap. Even with an air gap of only a few thousandths of an inch, proper care, which means nothing more than the right kind of oil in the bearings and the right amount at the right time, will prevent the rotors wearing on the stators, if the

[1] Consulting Electrical Engineer, Chemical Building, St. Louis, Mo.
[2] Electrical Engineer, Wagner Electric Manufacturing Co., St. Louis, Mo.

bearings are designed liberally enough. The latter point is therefore a very important one to the purchaser of an alternating-current motor.

WILLIAM H. BRYAN. The State Railway Commission of Wisconsin has been doing some admirable educational work towards a better understanding of the ready-to-serve charge. It is fixing rates for all the utilities in that state, and doing it very thoroughly and well.

I do not like Mr. Robbins' method of charging depreciation as outlined in Appendix No. 4 of his paper. This method, which he says is in general use in appraising shop tools, is to charge off a certain percentage each year. He gives it as 10 per cent, which I find very common figure. A tool may thus be thirty or forty years old and still have book value. The more modern way of handling depreciation is the sinking-fund scheme, by which the probable life of the tool is first estimated, by a study of its service, and then an amount is set aside each year, which will, with interest compounded annually, at the end of the assumed period of life, have replaced the full value of the tool. To ascertain the value at any intermediate date the amount of the accumulation in that fund is deducted from the cost of duplicating the tool.

H. WADE HIBBARD. I recently visited the St. George Street plant of the American Car and Foundry Company in St. Louis, where electric driving is applied to a wide range of work. That plant, engaged in the manufacture of steel cars, is very large and compact. Since it is engaged in the manufacture of a large number of parts that can be produced on a factory basis, they have adopted alternating-current motors. The large machines are individually-driven, and the small machines are group-driven.

HENRY HESS. I cannot agree that the direct-connected motor drive is always and everywhere the only correct thing; nor do I reject it absolutely and utterly for every shop, place and tool. Both attitudes are too radical and sweeping; truth will be found as usual between the extremes.

The direct-connected motor drive is distinctly preferable where any advantage in quantity of output results from its use, or where a machine is to be portable, or is so located that it can be reached only by long or awkward lineshaft and belt drives. Under every other condition the individual motor drive is more expensive in initial

installation and upkeep, and more complicated to maintain in the average shop.

The absence of overhead and vertical belting is an advantage that appeals to the extremist. The amount of light obstructed is inappreciable, be the shop of the modern well-lighted type or one of the older dark interior. The horrible example which Mr. Riddell shows (Fig. 21) is most carefully selected; but is not necessarily representative. In contrast note Figs. 37 and 38 herewith. Here are six parallel rows of lathes in a shop bay 50 ft. in width. The two side rows are driven from lineshafts carried on the crane columns. The four central rows are driven from two lineshafts that are mounted on cast-iron columns standing free of the building. Cross-arms from these support longitudinal channel beams to which the countershaft hangers are attached. The lineshafts are driven by alternating-current motors back-geared to the shafts. Note also the utilization of the crane-track girders for carrying the lineshaft that drives tools close to the crane columns. These lineshafts are also direct motor-driven. There is no interference with the overhead traveling crane. Not the most rabid advocate of light has ever been able to criticise this installation for lack of it. Nor is there any noticeable interference with lighting when there is an overhead ceiling as in Fig. 39. Here again the lineshaft is driven by a motor attached to the ceiling.

Even eliminating all of the many establishments that could not fairly be classed as progressive, provided the test of progressiveness is not based on the direct-connected idea, an examination of the machine shops in a given city will fail to show the prevalence of the direct-connected individual drive, whether the comparison be based on the number of shops, the number of machines, or the power transmitted. The conditions found in one city will be found true of others and of the country districts as well. The lineshaft and belting manufacturers are not yet losing sleep or going into the hands of receivers.

Whenever increase in capacity is directly attributable to the individual motor drive, that should be installed; but in each case it should be carefully considered whether the same increase in capacity cannot be secured without it. Then the relative cost of initial equipment and maintenance should be the deciding factor.

The shop manager not interested in what his operation costs is likely soon to receive emphatic reminder that his lack of interest is not shared by those whose dividends are affected. Every possible saving should be taken advantage of, every element of cost should be reduced if possible.

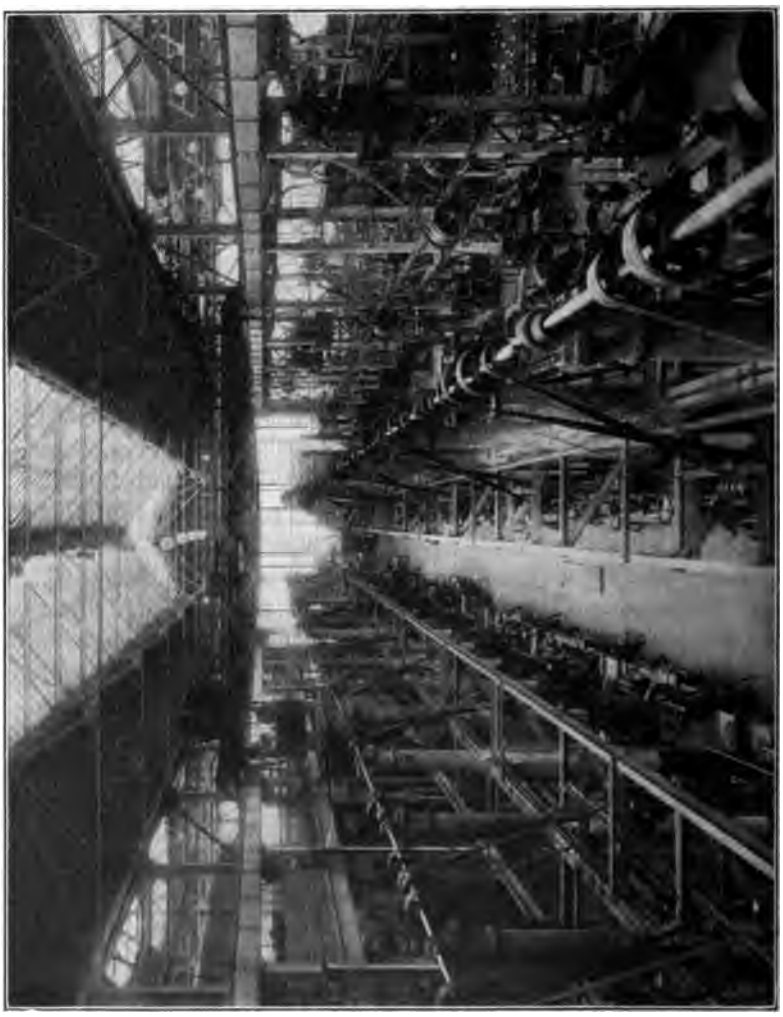


FIG. 37 BELT-DRIVEN MACHINE SHOP FROM ABOVE

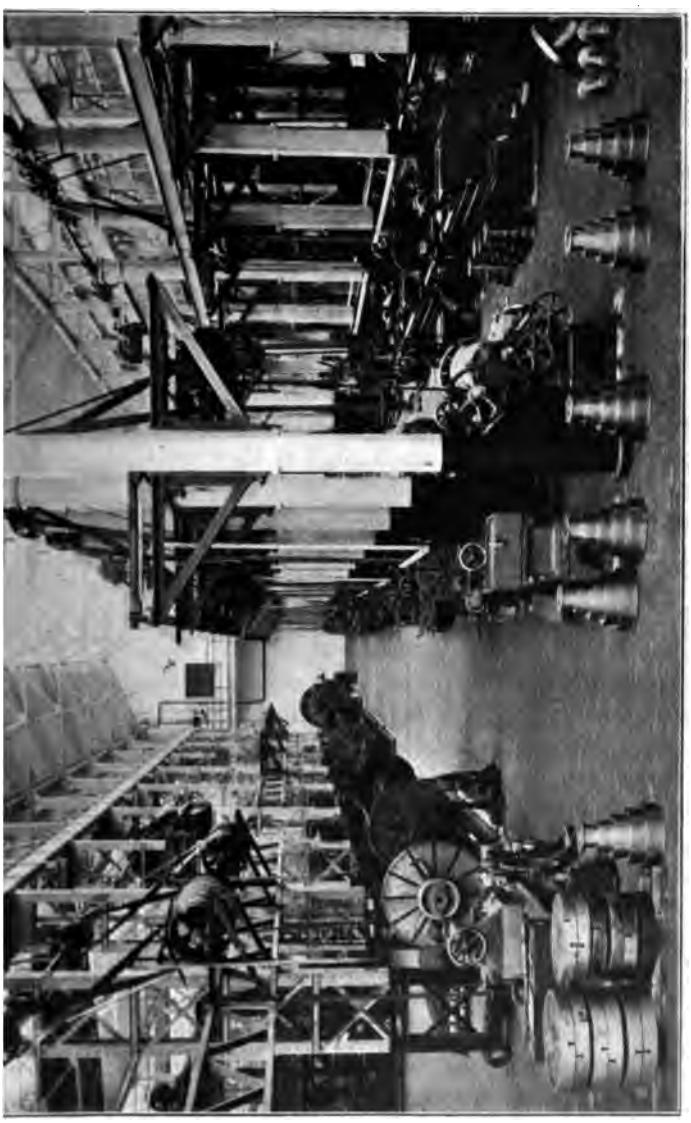


FIG 38 SAME AS FIG. 37 FROM BELOW

As producing engineers, we are all necessarily interested in advocating the particular thing we produce or help to produce. So far as my advocacy of the ball bearing is concerned, however, that does not predispose me toward the ball-bearing lineshaft, for the simple reason that the ball bearing is quite as widely employed on electric motors as on lineshafts.

Can the most thorough-paced advocate of the electric motor claim for it that it delivers more power than may be transmitted through a belt? Should one be found possessed of sufficient temerity, then what explanation has he to offer for that species of direct-connected motor drive in which a belt is interposed between the motor and the machine? Many such are to be found in the shops of the best equipped motor manufacturers, who, believing in the most thorough way in adopting what they advocate for others, equip throughout with motors to the exclusion of all lineshafts. Certainly these manufacturers and their shop managers do not go to the length of sacrificing capacity merely to be consistent, but they get that result in many cases through belts, and even through belts plus the despised countershaft, with the motor thus twice removed from the direct connection (see Figs. 25 and 29, of Mr. Riddell's paper).

Moreover, with belt drive the machine-tool manufacturer can build his machines in large lots without having to individualize for the almost endless diversity in electric motors. Attention has been called to the difficulties in reconciling the diametrically opposed needs of the electric motor and the machine tool. All of these difficulties are solved by the gear box already in more or less general use by many machine tool builders. It may be driven by either a direct current or an alternating-current motor or by a belt from a lineshaft or countershaft. All it asks is that the motor or belt be of sufficient size to satisfy its hunger for power.

A motor is many times more costly than a belt, wastes far more power in journal friction and windage alone than the belt uses up, and in addition has great electrical losses. Mr. Robbins, in advocating the motor, admits a motor waste of one horse-power to every three usefully delivered. What belted drive can be accused of similar wastefulness and inefficiency? Remember also that the belt drive does not vary in speed even by a few per cent. Can that be said of the electric motor? Even its advocates have admitted the contrary.

Great credit is due the manufacturers of electric machinery for having given an impetus to the art of economical machine production. They have not only stimulated the advance through constan

demand on the machine tool builder but they have also shown him the way by example. Naturally they have made the widest possible use of that means of power transmission which constitutes one of their staples of manufacture. That has focussed attention on the methods they advocate. Other methods no less meritorious, or even superior, with no such strenuous and interested advocates have not been similarly brought to public attention, and possibly have not felt the need.

The essential matter which the man responsible for final costs must weigh is not that of direct-connected individual motor drive, or of any other drive, but that of final total cost as influenced by all factors. So far as the transmission and application of power are concerned, it is a matter of largest output at least cost. It must be by motor if that gives more output than can be realized by shaft and belt. It must be by shaft and belt if that can give as great an output as the motor. The decision must so fall, simply because of lower first cost and lower upkeep cost.

Stress has been laid in the papers on the economical features of the direct electric motor drive. Whenever such application results in increased output, due to qualities inherent in the electric motor, then the direct motor drive is in order. Whenever the direct motor application does not inherently reduce operating time, then investigation is in order to determine whether the line-shaft drive is not more economical and the direct motor application a compliance with a fad to be dearly paid for.

The impression given by the papers is one of the all-round superiority of the direct-connected motor. It is only in the following instances, however, that the individual motor drive overbalances the economic features of the lineshaft:

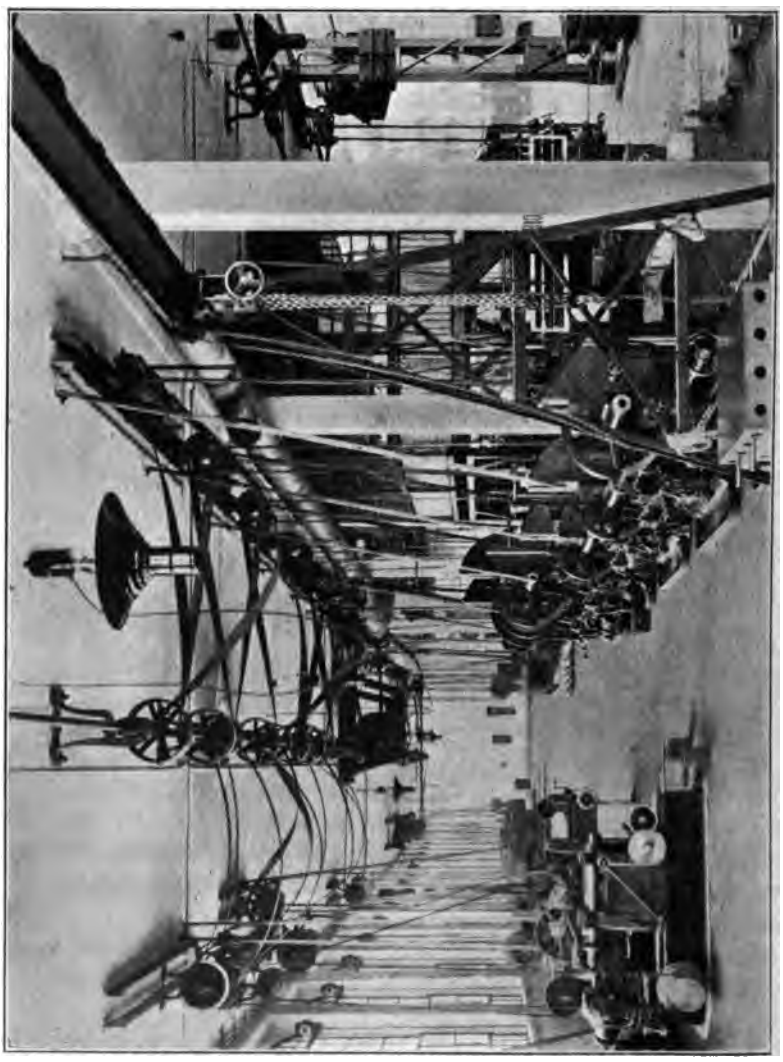
a Where machine portability is important.

b Where relative under-equipment with large machines makes their overtime operation necessary, while the balance of the plant is idle.

c Where occasional machines can be reached only by long lines of shafts or are inconvenient to drive from the line-shaft.

d Where the direct motor application results in increased productive output not otherwise obtainable.

In every other case the lineshaft has the advantages of lower first cost, lower cost of maintenance, smaller depreciation, less power waste and less grand total of annual costs.



Moreover, the differences are very decided. This is true even when the lineshafts are mounted on plain bearings, with their large friction wastes. It is still more true when these friction losses are reduced by mounting the lineshafts on ball bearings of a durable type. The difference is still further increased in favor of the lineshaft when it is run at the high speed that ball bearings make feasible. High speed decreases weight of shafting, weight of pulleys, weight of belts, and with these the journal loads and losses, as well as the first cost of every element in the system.

Realising that definite figures rather than general statements are wanted, I have made direct quantitative comparisons, using as a base an existing, well-arranged plant of direct motor-driven machine tools. For this purpose our former president, James M. Dodge, placed the data and experience of the Link Belt Company's works at my disposal.

Fifteen representative machine tools cost for motors $4920; for power annually at $0.03 per kw-hr. $2930; for depreciation at 10 per cent and maintenance at 5 per cent $492 and $246 respectively. The total annual cost is $3668

A lineshaft installation at 200 r.p.m. on plain bearings would cost only $520 initially and take $170 less annually for power, with a total annual cost of only $2838, or $830.00 less.

The same lineshaft, but carried in ball bearings, would cost only $790 initially, save $330 in power annually and involve a total annual cost of only $2718, or $950 less.

Increasing the lineshaft speed to 600 r.p.m. and carrying this in ball bearings gives the most economical arrangement at an initial cost of only $460, an annual power charge reduced by $750 and a total annual cost of but $2249, or $1419 less.

Such a high-speed ball-bearing lineshaft system costs less than one-tenth as much to purchase as a direct-connected individual motor system, while involving less than two-thirds the latter's annual charges. Even this can be bettered materially by the employment of ball bearings in the countershaft and loose pulleys.

The data on which the foregoing is based are given in detail in the Appendix herewith, based on the tabulation, Table 19, of direct-connected machine tools in the shops of the Link Belt Company's plant, at Philadelphia.

APPENDIX TO DISCUSSION BY HENRY HESS

REFERENCES TO TABLE 19

As the total load factor in Table 19 is 17.0 per cent of the total motor rating, the total useful power delivered is $167 \times 0.17 = 28.4$ h.p.

In Par. 126 of his paper Mr. Robbins allows for the low load factor of direct-connected motors by assuming an average motor efficiency of 75 per cent. But this is not the whole story. Some prime mover, as a steam engine, must first drive an electric generator and the current must then be conveyed to the motor by wires. The generator efficiency will average 92 per cent and the line transmission 95 per cent. This makes a combined average efficiency for the generator, line and motor of $0.92 \times 0.95 \times 0.75 = 0.65$.

Using this value gives $\frac{28.4}{0.65} = 43.6$ h.p. as the average total power consumption.

The cost varies with local conditions, but will rarely be less than 3 cents per kilowatt-hour, making the power cost for a year of 300 days at 10 hours = $0.03 \times 43.6 \times 0.746 \times 3000 = \$2930$.

TABLE 19 DIRECT-CONNECTED MACHINE TOOL DATA

Motor No.	Motor Rating Horse-Power	Load Factor Per Cent	Motor Cost Dollars	Machine
43	25	14.4	583	120-in. vertical boring mill
42	25	12.0	588	84-in. vertical boring mill
76	9	16.6	268	37-in. vertical boring mill
99	9	16.6	268	30-in. vertical boring mill
100	9	15.6	250	Keyseater
61	3	20.0	159	Drill press
60	8	27.5	303	Keyseater
72	8	21.3	237	Keyseater
46	18	20.0	477	20 in. × 49 ft. lathe
44	12	8.3	440	30 in. × 27 ft. lathe
62	3	16.7	159	Cut-off lathe
104	12	14.2	440	Milling machine
39	9	36.5	263	Planer
59	8	18.8	237	Side planer
66	9	15.5	250	Screw cutter
Total	167	17.0	$4922	

REFERENCES TO TABLE 20

The lineshaft and countershaft journal losses in Table 20 are based on a ratio of 1.94 to 1, in accord with Flather's findings of average machine shop conditions as quoted in Kent's Pocket Book, 4th edition, p. 965.

REFERENCES TO TABLE 21

The loss of 13.2 h.p. on plain bearings in Table 20 is incurred by the line-shaft journals and the countershafts; it is reasonably accurate to apportion

TABLE 20 LINESHAFT DATA AT 200 R.P.M. WITH PLAIN RING-OILING BEARINGS

Shaft diameter $2\frac{1}{16}$ in. safe for 100 h.p. usual catalog rating	Cost
Shaft length 100 ft	$65.20
Main drive belt 14 in. by 30 ft	90.62
Main pulley 56 in	26.77
13 hangers, 36 in. drop with ring oiling bearings	81.60
15 double pulleys on lineshaft	37.25
15 sets of belts to drive countershafts	217.71
Total	$519.15

Useful power delivered to the machines, as with the motors	28.4 h.p.
Lineshaft and countershaft journal losses	13.2 h.p.
Total	41.6 h.p.

Total annual payment for power at $0.03 per kw-hr. and 3000 hours
= 0.03 × 41.6 × 0.746 × 3000 = $2700.00

TABLE 21 LINESHAFT DATA AT 200 R.P.M. WITH BALL BEARINGS; OTHERWISE AS IN TABLE 20

Shaft	$65.20
Main belt	90.62
Main pulley	26.77
2 D Hangers, with medium weight ball bearings next to main pulleys	80.34
10 C Hangers, with light weight ball bearings	269.90
15 pulleys on lineshaft	37.25
15 sets of belts to drive countershafts	217.71
	$787.79

Useful power delivered to the machines, as with the motors	28.4 h.p.
Lineshaft and countershaft journal losses	10.9 h.p.
Total	39.3 h.p.

Total annual payment for power at $0.03 per kw-hr. and 3000 hours
= 0.03 × 39.3 × 0.746 × 3000 = $2600.00

TABLE 22 LINESHAFT DATA AT 600 R.P.M. WITH BALL BEARINGS

Shaft diameter $2\frac{7}{16}$ in. safe for 96 h.p. usual catalog rating	
Shaft length 100 ft	$ 48.00
Main drive belt 10 in. by 30 ft	64.80
Main pulley 36 in	10.19
2 B hangers 18 in. drop with medium-weight ball bearings next to main pulley	34.68
10 B hangers 18 in. drop with light-weight ball bearings	150.00
15 double pulleys on lineshaft	19.41
15 sets of belts to drive countershafts	129.52
Total	$456.60

Useful power delivered to the machines as with the motors	28.4 h.p.
Lineshaft and countershaft losses	4.1 h.p.
Total	32.5 h.p.

Total annual payment for power at $0.03 per kw-hr. and 3000 hours
= 0.03 × 32.5 × 0.746 × 3000 = $2180.00

this equally between the two. Ball bearings will save, under average conditions, if other conditions remain unchanged, about 35 per cent of the lineshaft journal loss. In this case, therefore, taking the 13.2 h.p. from Table 20, $\frac{1}{2} \times 13.2 \times 0.35 = 2.3$ h.p. This leaves a loss of $13.2 - 2.3 = 10.9$ h.p., as given in Table 21.

The loss could be reduced by another 2.3 h.p. by mounting loose pulleys and countershafts on ball bearings; but as these parts are generally furnished with the machine it is relatively difficult to secure them so mounted. It must be remembered that it is the user and not the builder of the machine who secures the benefits of the ball bearing mounting and it behooves the user to specify accordingly and to insist on compliance.

REFERENCES TO TABLE 22

Referring to the useful power delivered to the machines, the total lineshaft load is now only

$$\frac{1\frac{1}{16} \times 7110 \times 600}{12 \times 33{,}000} \times 0.0015 = 1 \text{ h.p.}$$

owing to the reduction in weight of the shaft, pulleys and belts and also the reduction in pull of narrower high-speed belts to 7110 lb.

The countershaft total load is 5000 lb., speed 400, but the friction is high at about 0.08 as conditions are not as good for the plain journals of the countershafts. This gives a loss of

$$\frac{2\frac{7}{16} \times 5000 \times 400 \times 0.08}{12 \times 33{,}000} = 3.1 \text{ h.p.}$$

Total loss = 3.1 + 1 = 4.1, as in Table 22.

L. R. POMEROY. In Par. 95 of his paper, Mr. Robbins states that the alternating-current motor is essentially a constant-speed machine The variable-speed alternating-current motor, possessing series characteristics, is not adapted to general machine tool driving, but it can be used to more or less advantage to perform operations to which a series motor is adapted, such as driving bending rolls, cranes etc. In a number of tools it is advantageous to vary the speed, to stop, start and reverse quickly in order to facilitate lining up the work, to take a trial cut, to adjust counterbore, etc. After such adjustment the open or synchronous speed can be used for cutting and the tool then becomes, through its working cycle, essentially a constant-speed machine. The additional speed changes, as outlined are valuable as time savers and are justified from this standpoint yet it is not necessary to drive with a direct-current motor.

The references in Par. 96 and Par. 149 to geared-head machine or tools equipped with mechanical speed variation hardly do justice to these tools, as the speed-changing mechanism in many of them i

as available and handy as if obtained electrically and, therefore, removes the necessity for individual drive for a tool located in a department group. There is no question that, from a commercial viewpoint, the alternating-current motor is preferable for constant-speed work, on account of economy of transmission, ease of obtaining proper voltage for lighting, and the general cost of upkeep of motors. As an example of this latter point, the case of a large manufacturing concern in the Middle West is pertinent. The shop is provided with both direct and alternating-current motors, and the cost of upkeep is $2 per month more for the 600 h.p. in direct current than for the 4000 h.p. in alternating current.

For railroad shop conditions 75 per cent of all requirements can be fully met by constant-speed motors and as the necessary 25 per cent of direct-current motors for the variable-speed machines can be obtained by the use of a motor-generator, it would seem that this is the most desirable combination to use. By providing a synchronous motor for driving the motor generator, an excellent opportunity is given to adjust or to increase the power factor, thereby eliminating the low power factor and its consequent disadvantages. The synchronous motor, besides delivering leading current and neutralizing a low power factor, has 70 per cent of its capacity available for mechanical load, and as this part of the load can be utilized to supply the necessary direct current for variable-speed tools, the combination becomes an efficient one. Alternating-current motors are especially economical and advantageous in wood-working shops on account of the presence of dust and flying particles. If direct-current motors are used, the fire hazard necessitates the use of enclosed motors, which are much larger for a given output, on account of the restricted ventilation due to enclosing.

As an illustration of the advantage of reckoning with the intermittent duty of a given machine in determining the size of motor to select for a given service, suppose the requirements are 50 h.p. for five minutes, 10 h.p. for ten minutes, the cycle to be repeated every 15 minutes with speed constant. The speed characteristics of the motor require a shunt excitation, i.e., a definite exciting current in the fields regardless of the load on the armature. The average motor load is

$$\begin{aligned} 50 \text{ h.p.} \times 5 \text{ min.} &= 250 \text{ h.p. min.} \\ 10 \text{ h.p.} \times 10 \text{ min.} &= 100 \text{ h.p. min.} \\ \text{Total,} & \quad 350 \text{ h.p. min.} \end{aligned}$$

$$\text{or, } \frac{350}{15} = 23.3 \text{ h.p. average.}$$

The average load will not produce the heating that the cycle will, for the reason that the copper loss varies as the square of the current. The root mean square or equivalent heating will be produced by the following:

$$(50)^2 \times 5 \text{ min.} = 12{,}500 \text{ (h.p.)}^2 \text{ min.}$$
$$(10)^2 \times 10 \text{ min.} = 1000 \text{ (h.p.)}^2 \text{ min.}$$
$$\text{Total, } 13{,}500 \text{ (h.p.)}^2 \text{ min.}$$

Dividing this power by 15 minutes gives the average square as 900, the square root of which is 30 h.p.

$$\sqrt{\frac{13{,}500}{15}} = 30 \text{ h.p.}$$

This is the root mean square load, or a load which will produce the same heating if applied continuously as would the intermittent work.

Group driving, employing relatively short main and counter-shafting, is not an unmixed evil for the reason that the aggregate stored energy of pulleys, due to flywheel action, is advantageous where slotters, shapers, drills, planers, etc., are present, counteracting in a large measure the shaft friction losses. Very often a better load factor is obtained from the group motors than from the aggregate intermittent service of the individual-drive motors. The repairs on individual-drive motors are heavier than for the same number of group-drive motors. As an illustration, a certain shop has the same number of motors as one of 70 per cent greater capacity located in another city, both shops producing the same kind of output. In the former case individual drive is the rule; in the latter group driving prevails. The repairs per unit of output are larger in the former than in the latter.

7 It is also quite necessary to consider the work to be performed by a given tool in a given department, rather than the range of the tool. For example, a 72-in. boring mill has an ultimate range of work from 72 to 3 in., and with various materials a cutting-speed range of 15 to 25 ft. per min. The total speed range therefore becomes

$$\frac{72 \times 25}{3 \times 15} = 40 \text{ to } 1$$

Where the variety of work a tool will perform is the determining factor a wide range of speed quickly obtained is desirable, but under ordinary machine shop conditions, volume of output is the standard governing the selection of a tool, requiring in many cases constant speed.

The ideal condition is when the work is so classified and arranged that the machine is performing practically the same work all the time, i.e., duplication of parts. This condition requires the minimum amount of speed manipulation, at least that which is electrically obtained. The more variable speed is sought for, the further we are getting from ideal conditions. This should promote judicious conservatism and careful analysis to make sure of definite reasons for departure from the ideal standard. A careful study of each tool, with reference to the work to be performed, will establish definite ranges of speed, which will be found quite narrow, and which automatically determine the power requirements. The selection of the driving motor would be governed by the foregoing conditions, and might not apply to the same kind of machine in another shop or even in another department of the same shop, where a different output prevailed.

Mechanical changes of a simple character, not covering a very wide range but grouped about the zone of work for which the tool is generally intended or selected to perform, giving changes within comparatively narrow limits, provide variations that are useful and advantageous. This avoids the necessity of using motors with large speed ranges and very often admits of the application of a constant-speed motor, where otherwise a variable-speed motor might be required, all of which tends towards economy in first cost and repairs.

The results of comparison vary, depending upon whether the tool output is based on performing stunts or ordinary commercial shop operations. In forge shops at steel plants, where no attempt is made to forge close to size and the machine tools are relied on quickly to reduce the forgings to rough-finished sizes, or where motor shafts are rough-forged and then finished on machines, the question of high-speed cutting tools and powerful machines is of the greatest importance. But in railroad shops where the companies purchase driving axles, crank pins, piston rods, etc., rough-turned with a flat-nosed tool to within one-eighth or one-sixteenth of an inch of finished dimensions, an entirely different standard necessarily governs the rating of tools, both as to power and speed requirements. For instance, in a list of parts, 23 in number, scheduled for manufacture at the central or main shop of a large railway, the arrangement is such that the minimum amount of machine work has to be performed at the local or division shop where the repairs are to be made. Piston rods are finished except piston and crosshead fits, crank pins are finished complete except for wheel fit, etc., all of which goes to show that a large quantity of work, at least in railroad shops, requires minimum rather than maximum machine tool duty.

The heavy type of so-called high-speed lathe is practically built for forging lathe conditions and under these conditions requires high power to drive it, but when, as is frequently the case, this same tool is installed in a railway shop where much smaller cuts are the rule, it is not necessary to provide for such great power, as the full capacity of the tool is never utilized.

In order to utilize the full power of such a machine, it is necessary to raise the cutting speed in the same proportion as the area of the cut is reduced, but this is not always possible. For example, a $\frac{3}{4}$ in by $\frac{1}{8}$ in. cut was taken at 38 ft. per min., while with a cut of $\frac{3}{16}$ in by $\frac{1}{8}$ in. only 52 ft. per min. could be obtained. With one-half the area of the cut, the cutting speed could be increased only one-third resulting in the removal of only 57 per cent as much metal. If the full capacity of the machine is not possible, why pay the price for a high-power motor when a saving in first cost is possible by the selection of a motor more suitable and a better efficiency can be obtained by running the motor more nearly up to its normal capacity? A 1 per cent loss in efficiency on a 15-h.p. motor capitalized at 10 per cent per annum would amount to $750. The same policy carried out among a large number of machines would result in a considerable saving.

The formula in Par. 185 can be simplified and made more workable if stated as

$$\frac{\text{diameter} \times \text{r.p.m.}}{3.82}$$

This affords a very expeditious method of finding by the slide rule the cubic inches of metal removed per minute, which equals diameter $\times$ r.p.m. $\times$ 3.15 depth by feed. Substituting the values given by Mr. Robbins, we have $5.5 \times 45 \times 3.15 \times 0.45 \times 0.06 = 21$ cu. in.

GANO DUNN.[1] It is not a question of whether or not we should have electric motor drive in a machine shop, but what kind of drive. If what Mr. Hess said is true, most of us are wrong, yet I think I am within the facts when I say there are very few machine shops built today that are not electrically driven. If we adopted Mr. Hess' methods of equipping a factory, we should have the conditions shown in Fig. 21 of Mr. Riddell's paper. It is obvious that his form of machine shop is obsolete.

After all, the cost of power in our plants is not the principal que

[1] Vice-President, Crocker-Wheeler Co., Ampere, N. J.

tion. Some years ago I gathered figures which showed that the cost of power in the average machine shop was only about two per cent of the value of its product. That indicates that questions of saving in power are of minor importance.

With Mr. Hess's suggestion, where should we come out on the other vital part of the question, the capacity or output? The day of the electric motor in a machine shop is the day of the red-hot chip. It has driven out belts in the same way that it has driven horses from the front of street cars. It is successful, it is practical, and it is the one thing that fills all our wants, because it gives us all the power we want, where we want it, when we want it, and as we want it.

Mr. DeLeeuw's paper and Mr. Robbins' paper are dictionaries of the art of electric driving. In connection with the classic paper of Mr. Taylor, On the Art of Cutting Metals, we now have a reference library to which we can turn for almost any question likely to come up.

I do not believe there is any specific rule that can be laid down to guide an engineer in the layout of a machine shop. Each case must be decided on its own basis. My view of how much power it takes to run a particular machine tool is that it depends on who is the superintendent of the shop. The problem is principally one of capacity. The enormous capacity we can put into a tool by means of the electric drive, to say nothing of all the other advantages that have been rehearsed, it seems to me not only settles the question now, but will continue to settle it.

In the very early days, when it was hard to get the attention of manufacturers to the subject of the electric drive, we had to use the argument that it saved power. Then there came a time when it was admitted that electric motors were good for ordinary work, but could not drive rolling mills. And now the climax of rolling-mill development is capped when we see a 6000-h.p. induction motor driving the mill at Gary. I feel that we have now closed the first chapter on the art of the electric drive in machine shops.

FRED. L. EBERHARDT, Vice-President of the National Machine Tool Builders' Association, gave a summary of the progress made toward the standardization of motors for machine tools by a committee from his association in conference with one appointed by the American Association of Motor Manufacturers. Fifteen points were proposed for discussion by the former committee, of which seven were agreed upon and have since been adopted by the motor manufacturers. The remaining eight are still being studied and discussed. The following

quotations from the report of the committee on standardization of motor drives for machine tools to the Rochester convention of the National Machine Tool Builders' Association, May 24, 1910, outlines the present situation:

1 *Horse-Powers.* It is thought that the following horse-powers will meet practically all the requirements of electric drives for machine tools: 1, 1½ (for D. C. only), 2, 3, 5, 7½, 10, 15, 20 and 25. Though it was agreed that horse-powers more than 25 and less than 1 are used, it was not thought advisable to embody them at the present in the attempted standardization.

2 *Voltage.* It is recommended that for D. C. motors 115 and 230 volts be adopted as standard, and for A. C. motors 110 and 220 volts. There is now a good deal of confusion as to voltages for D. C. motors. The motor manufacturers have reached an agreement among themselves as to these voltages, and the 115 and 230 voltages recommended by them represent the nominal voltage of the system, and not the real voltage at the motor.

3 It is recommended that the horse-power ratings for machine-tool drives be the standard ratings of the American Association of Electric Motor Manufacturers, i.e., (*a*) that motors be given the continuous constant horse-power rating where approximately standard load conditions exist; (*b*) for adjustable-speed motors used for intermittent service the standard two-hour continuous-duty rating be used for ordinary shop conditions and that the name plates of such motors indicate the time as well as horse-power ratings of the motor, and further that the horse-power be figured at the high as well as the low speed for adjustable speed service.

4 *D. C. Motors.* It is the recommendation of the joint committee that constant speed motors, adjustable speed motors with a range of 2 to 1, and adjustable speed motors with a range of 3 to 1, be included in the attempt at standardization. This does not exclude the occasional use of motors with a different speed range, such as 4 to 1, or even more; but it was the opinion of the committee that motors with a higher range of speed than 3 to 1 are not used to a sufficient extent and are not so absolutely necessary for machine-tool construction as to include them among the standardized motors.

5 The following table of speeds is recommended as the standard for adjustable speed D. C. motors:

h.p.	2 : 1	3 : 1
25	900—450	900—300
20	900—450	900—300
15	1200—600	1200—400
10	1200—600	1200—400
7½	1200—600	1200—400
5	1200—600	1200—400
3	1500—750	1500—500
2	1500—750	1500—500
1½	1500—750	1500—500
1	1500—750	1500—500

6 *A. C. Motors.* It is recommended that the following table of polyphase 60-cycle A. C. motors be adopted:

25 h.p.	900 and 600	5 h.p.	1200
20 h.p.	900 and 600	3 h.p.	1200
15 h.p.	900 and 600	2 h.p.	1200
10 h.p.	1200 and 600	1 h.p.	1800 & 1200
7½ h.p.	1200 and 900		

7 For the consideration of the constant-speed A. C. motors, 60 cycles is to be used as the basis.

8 *Shaft Diameter.* It is recommended that the shaft diameter be figured according to the formula $D = C\sqrt[S]{\text{h. p.}}$ in which C is a constant to be agreed upon by motor manufacturers, D the diameter, and S the speed; it is further desired that all diameters up to and including one and one-half inches be given in one-eighth of an inch, and all diameters above one and one-half inches be given in one-quarter of an inch.

9 *Length of Shaft.* It is recommended that there shall be a fixed proportion between diameter and length; the constant to be determined by the motor builders. Further, that the shaft be rounded at the end.

10 *Keyways.* It is recommended that keyways be made for square keys and that the key be equal to one-fourth the diameter of the shaft.

11 *Driving Fit.* It is recommended that there be added to the standard dimensions of the shaft 0.0005 in. for every half-inch diameter of the shaft or fraction thereof.

12 *Variation.* It is recommended that shafts shall not be under the specified size, but may exceed same by 0.0005.

13 *Height of Centre.* The height of center to be given in full one-fourth inch, and shall not be less than figured dimension, but may exceed this dimension by one thirty-second.

14 *Clearance Circle.* It is recommended that the clearance circle around the motor shall have a diameter of one-half-inch less than twice the centre height.

15 *Base.* All motors to be held down by four bolts. Bolt holes to be drilled one-sixteenth above size of bolt required. Bottom of motor to be planed parallel with the shaft of motor. It is further recommended that the bolt holes be placed in a configuration of constant proportions, preferably in a square, and that the dimensions of this configuration be made a function of the horse-power divided by the speed, and further that all dimensions be given in the nearest higher one-fourth inch. The feet of the motor should extend beyond the body sufficiently to allow for drilling and reaming of dowel pin-hole while motor is in place.

DISCUSSION AT NEW YORK

CHARLES FAIR.[1] It is disappointing that so many of the tool builders fail to take advantage of the increased production which would result from proper attention to convenience of control. There are many cases where the tools are so arranged that the control

[1] General Elec. Co., Schenectady, N. Y.

might easily be damaged by trucking, etc., and sometimes the c is placed 40 or 50 feet away from the motor, necessitating consid useless wiring. Others often place the operating handle in s position as to make a back-breaking job for the operator.

For electrical reasons it is of course not practical to build r with a ratio so great as 15 to 1, nor can I agree with Mr. Ebe that such a large ratio would be desirable or necessary for a larg jority of the work. The standardization of speeds and pri dimensions is not impossible, but that the tool builders wou satisfied with any standard is not at all probable, inasmu there is a decided difference of opinion among them as to both s and shapes of motors.

An unfortunate circumstance which often surrounds discu relating to electrical apparatus for tools is a lack of knowled either side of the limitations and requirements of the other. of the trouble which tool builders are experiencing today be eliminated were they to discuss their difficulties more freel men who are conversant with both sides of the subject.

A. L. DeLeeuw. Generally speaking, the machine tool builde not know to what purpose his product will be applied by the cons It is true he knows in a general way that a lathe will be used fo ing and a drill press for drilling, but he has no knowledge of the m employed in the shop where his product is to be used, nor wh his machine will be used for general work or for some special tion. The machine may never be called upon to work up to its mum capacity, and yet it may be called upon to do this all the If the machine is to be supplied with a motor, the only safe th to attach a motor of sufficient capacity to run the machine all th up to its maximum output. Even if it is known that the ma will be used for light work by the man who buys it, yet it may time come into other hands and be used for entirely differen poses. Hence, unless the machine is supplied with a sufficientl motor, the design may be condemned at some time.

It is true that in general machine tools do not operate at maximum capacity or even at the rated capacity of the attached more than one-third to one-fifth of the time, so that in the ma of cases a much smaller motor can be used than would be requ the machine were constantly working at full capacity. Howeve machine tool builder has no guarantee that this general rul apply to his machine. The tendency nowadays is to specialize

use of machine tools and to subdivide operations in the shop. Whereas a few years ago it was the custom to give a shaft to some lathe hand to be turned and let him finish all operations on this shaft, preferably in one setting, now it is more common practice first to rough a lot of shafts, then finish them in a subsequent operation, and then perhaps grind them for a final finish. Wherever it is possible to do so, these operations are again subdivided.

The subdivision of operations, when carried out to its limit, makes operations in the shop extremely simple, requiring no adjustments of feeds or speeds while a lot is run through the machine, and calling for only a single tool. Where operations are carried through in this manner it is often possible to make them continuous. By this is meant that the process is so arranged that both machine and man are working all the time, or at least practically so. The vertical milling machine, for instance, in milling flat surfaces, may do so with the use of a rotary table and a multiple fixture mounted on this table, whereby it becomes possible for the operator to load and unload one piece while the cutter is acting on another piece. In this case the feed is adjusted to such a rate that the operator has just time enough to load and unload while the cutter passes over one piece. Where the piece is so small that the time for cutting is materially less than for loading, more than one operator may be used on such a machine; where it is much more than for loading, one operator may attend to two or three machines. In all cases the highest attainable economy is reached when both operators and machines are working all the time, and the rate of work should be such that the machine can keep it up without breakdown, and the tool not need an excessive amount of regrinding, nor the operator be fatigued by too rapid work.

Though the example given above is perhaps the most perfect application of this system of continuous operation and though rotary fixtures cannot always be applied, there are various means by which this same degree of efficiency can be approximated. The table of the milling machine may be given a reciprocating motion, either automatically or by the hand of the operator, at the end of each cutting stroke. In this case two fixtures are used. Again, a single fixture may be used with two loading fixtures, which can readily be clamped in the stationary fixture on the table of the milling machine, so that only a very small amount of time is lost between cutting operations. The relative cost of labor and machine burden would determine whether it would be better to slow the feed down so as to give the operator

time to load a fixture or whether two operators should be emp for one machine.

The same degree of efficiency can often be reached in operations by providing the operator with two mandrels and and shading the cutting operations down to a point where the ti cutting is just slightly longer than the time for removing a piec one mandrel and loading a new one. Here again two operator be employed or one operator may run two machines. There are cases where the time of the cutting operation is considerably l than the time required for preparing a new piece for the ma In such cases it may often be found advantageous to divide the c operation into two parts so as to have the time for cutting more equal to that for loading. In a similar way, efficiency on the gri machine can often be reached by grinding in two operation rough and the other for finish. Drilling also lends itself in many to the application of this plan, especially where gang drills are

The application of this principle of keeping both machine operators busy all the time at their maximum efficiency leads to interesting problems in the machine shop and could be carried much further than is done at the present time. The applicat this system, however, imposes much heavier duty on the m tool, and would not allow, therefore, of applying to such tools n which have been rated on the assumption that they will not be upon for more than two hours continuous service.

CARL G. BARTH. The various advantages of motor drive belt drives have been thoroughly and ably set forth, but I cam go unchallenged the claim of closer speed regulation.

While speed controllers of motors are frequently arrang give successive speeds varying nominally by as little as 5 pe the variation in speed consequent on a variation in load is so as to make it practically impossible to tell beforehand what con point must be used to insure a predetermined cutting speed for a piece of work, as required by the most advanced shop manag of today.

As an exponent of such management I have therefore been to remain an advocate of belt drives in preference to indi motor drives; for if a belt is properly cared for and not requi transmit an undue amount of power, its speed variation wit variation is only a fraction of that of an individual motor und same conditions.

This does not mean that I never advocate individual motor drives, for frequently the real advantages of such drives are so great as to outweigh entirely the consideration of the greatest constancy of speed. I hope the time is not far away when motors will be built at a reasonable cost that will be so nearly constant in speed at all controller points, regardless of load, that they will possess incontrovertibly all the advantages claimed for motors in the papers before us.

In fact, I have recently learned of a company that expects soon to put on the market a line of 3-to-1 adjustable-speed motors with no greater variation then 4 per cent in any part of the entire range of speeds and loads. If these motors actually materialize, a great step will have been taken towards the millenium of the machine shop engineer vitally interested in cutting speeds. But nothing is yet in sight that promises entirely to replace the belt.

JOHN RIDDELL. Ball bearings are undoubtedly very valuable, but nothing has been said about the quantity of belts required to go with lineshafting in an establishment like the General Electric Company. I pointed out in my paper by very conservative figures that had we continued putting in lineshafting, countershafts, hangers and belts, we would use approximately 6½ miles of lineshafting, about 4¾ miles of countershafts, 21,225 hangers, and about 80½ miles of belts. These figures were based on 8500 machine tools. We have in addition to this number possibly 2000 other machines, most of which are driven by motors. These would require many additional feet of shafting and belts, and a great many more hangers or roller bearings. We know from many years experience that the upkeep and attention required by such material are very great.

Machine tool builders seem to think that every electric motor is made for some machine tool, whereas less than 3 per cent of the motors turned out by the General Electric Company are used for this purpose. If the tool builders would standardize their tools so that the same motor would do for the same nominal size of lathe, milling machine, or any other machine tool, the results would be more satisfactory. It would be useless for us to undertake to standardize 70,000 or 80,000 motors when only about 2000 of them would be used for machine tools and these widely distributed over many types. It would not pay any concern turning out electric motors to attempt to standardize for machine tools, especially since they are rapidly being changed and developed. Many machine tools are made to double the work today that they did a few years ago, and had motors been stand-

ardized then they would have undergone constant changes. I from the standpoint of the middleman, being partly an elec and partly a mechanician, and knowing the difficulties fron sides.

H. A. HORNOR.[1] In a plant which requires a number of t large size for operating blacksmith, plate, angle, forge, patte joiner shops, the machine shop bears a less important relation total power consumption. For the operation of this class o constant-speed motors with heavy starting torque, capable o standing prolonged overloads, are satisfactory, as the work d require close adjustment of speed. With an ample power su alternating current the losses are reasonably low and are due i part to the variation of the product. Under these circums the induction motor can be used with great economy. It is thr the line and reversed with a simple knife switch, requiring no s compensator and permitting quick stopping and reversing. induction motor, if substantially designed, will withstand all the which severe duties demand and will cause little trouble or e A 50-h.p. squirrel-cage induction motor has operated a joggi chine for ten years with no other attention than the oiling bearings. The plant with which I am connected was equipp induction motors at the time when the individual motor dri an experiment and it may be conservatively stated that decade it has fulfilled every promise which its advocates clai its installation.

W. S. CHASE.[2] With reference to the statement in Par. 82 DeLeeuw's paper that variable-speed motors should always b with screw machines, our company has had on the market f years an automatic screw machine, usually driven by a sing all the speeds necessary for the production of any part being co within the machine beyond the point of application of powe electric drive it is merely necessary to supply a motor instead o and the motor may be of any type, alternating or direct-curr any standard make, and of constant speed. We believe t were the first to adopt this self-contained single drive on th matic screw machine, although similar machines have recentl placed on the market.

[1] New York Shipbuilding Co., Camden, N. J.
[2] Manager of Sales, National-Acme Mfg. Co., Cleveland, Ohio.

ENCE L. COLLENS, 2d.[1] I will limit myself exclusively to ble-speed direct-current motors and certain phases of their manufacturing machine shops, where the variable-speed e tool plays an important part in the process of manufacture. *bility of Speed Control.* In order to deal with definite instead of general statements Table 23 is submitted. This intended to give an idea of the average speed adjustments with belt-driven tools, or with gear-box-driven tools using t-speed motors. By belt-driven tools is meant tools having

TABLE 23 SPEED CHANGES ON TYPICAL MACHINE TOOLS

	Spindle Speeds or Cutting Strokes Per. Min.		Belt-Driven Cone Pulley Types				Gear-Box Types using Constant-Speed Motors			
			A		B		A		B	
	Total Range	Ratio	no.	per cent	no.	per cent	no.	per cent	no.	per cent
Lathe	3.5-350	1:100	10	66.8	24	22.2	8	93.0	12	52.0
Lathe	10-360	1:36	10	48.9	24	16.9	8	66.8	12	38.5
Drills	20-320	1:16	8	48.6	16	20.3	12	28.6	24	12.8
Miller	12-360	1:30	12	36.2	18	22.2	8	62.6	18	22.2
Boring Mills	2- 60	1:30	10	45.9	20	19.6	10	45.9	15	27.5
Shaper	6- 96	1:16	8	48.6	8	48.6	8	48.6	10	36.1
ross	12-300	1:25	8	58.4	8	58.4	8	58.4	16	23.9
entage jump at each speed change				50.5		29.7		57.7		30.4
centage which cutting or peripheral ist necessarily be below maximum if s doing a large range of miscellaneous				25.3		14.9		28.9		15.2

leys for speed control. Six representative tools are shown, tal range of spindle speeds or cutting strokes, indicated for ich I believe not only represents a fair average of the speeds h such tools are now designed, but also fully covers all the ients of the class of work for which each is intended. In of the lathes, two different ranges are shown, as it is hard to ngle ratio which will fairly represent all makes and classes.

ent, Reliance Elec. and Eng. Co., Cleveland, Ohio.

Under both the belt-driven tools and the gear-box tools, columns A and B represent, respectively, the minimum and the maximum number of speed changes found in standard tools of the types shown. In each case both the number of changes and the percentage jump in speed at each change are shown, assuming that the speeds are in geometrical progression. The average practice is more nearly represented by column A than by column B. In some cases the maximum number of speed changes for the belt-driven tools is greater than for the gear-box types, due to the use of countershafts arranged for two and in some cases three speeds.

Compare the figures indicated in the table with the results which can be obtained by using adjustable-speed direct-current motors. With the speeds in geometrical progression and a controller having 20 contact points for speed adjustment, the jump in speed between each step for motors with 1:2, 1:3 and 1:4 speed ratios will be 3.7, 6.0 and 7.6 per cent respectively. With the armature-shifting type of adjustable speed-motor there is of course no jump, the speed change being continuous.

From this definite comparison it is almost self-evident that there will be many conditions of work under which the use of the adjustable-speed direct-current motor will result in an increase in the productive capacity of the machine tool of at least 5 per cent, and in many cases 10 per cent, as compared with any form of group or constant-speed gear-box drive. In many cases the greater accuracy of speed adjustment will in itself produce such an increase, and when there is added the greater ease and convenience of making the speed change, the probabilities are more than doubled.

In large manufacturing machine shops using specialized tools and limiting each tool to practically single operations with very little change in the size and character of the work on each tool, the question of accurate speed adjustment is of lesser and in some cases of no importance, but this is not true of the medium-sized or comparatively small plants. In such plants there is not enough work of any one character to justify a specialized tool, and in consequence each tool of the variable-speed variety is called upon to work continuously over a wide and miscellaneous range of work. Does a 5 per cent increase in productive capacity justify for work of this character the use of the individual adjustable-speed motor?

In a small or medium-sized manufacturing machine shop, the average maximum power requirements per tool will usually run well under 5 h.p. Taking 30 cents per hour as the average rate of pay and

30 cents per hour as a fair and probably low overhead charge per tool, the total expense per tool per year of 3000 hours amounts to $1800. Using this figure, 1 per cent increase in productive capacity means an annual saving of $18 per tool.

Even taking into account the much lower capacity per tool of the group-drive motor, the difference between the cost of any form of group-drive installation and the individual-drive adjustable-speed motor, including the cost of mounting on the tool, will in some cases be as low as $200 per tool and will rarely exceed $350 per tool in a plant of the size under consideration. Assuming 15 per cent as the rate of interest and depreciation, an increase in productive capacity of from 1.7 per cent to 2.9 per cent will capitalize the additional investment, and from 11 to 20 per cent will pay for it in one year.

Even assuming that the plant rents power from some central station and is on the outskirts of a city where only alternating current is available, the additional cost of the motor-generator set will run from $30 to $60 per tool, depending on the size of the plant and the number of variable-speed tools. With the 5-h.p. maximum motor capacity per tool, the generator capacity will be about 2 kw. per tool. An increase in productive capacity of from ¼ to ½ per cent will capitalize the motor-generator investment and from 2 to 3 per cent will pay for it in one year.

The total additional cost of the direct-current motors and generators, even taking the maximum figures given, will thus be capitalized by 3½ per cent increase in productive capacity. Five per cent increase in output means a saving equal to practically 25 per cent of the additional cost of the investment, whereas 10 per cent pays for the change in two years.

These figures are well within the possibilities of attainment. It is assumed, however, that the plant is crowded for work and is in a position to sell the additional output. This is a fair assumption, as I believe a plant which is not working full capacity would not be apt to consider any change in its power equipment. As Mr. DeLeeuw has said, an increase in the amount of chips per hour is a more vital factor than any relative saving or loss in different methods of transmitting power.

Speed Ratios for Direct-Current Adjustable-Speed Motors. In Appendix No. 3 of Mr. Robbins' paper, he has in all cases shown 1:3 as the ratio for adjustable-speed direct-current motors. I agree with Mr. Robbins that this will probably become the ultimate standard for many classes of machine tools, but I do not feel that it will ulti-

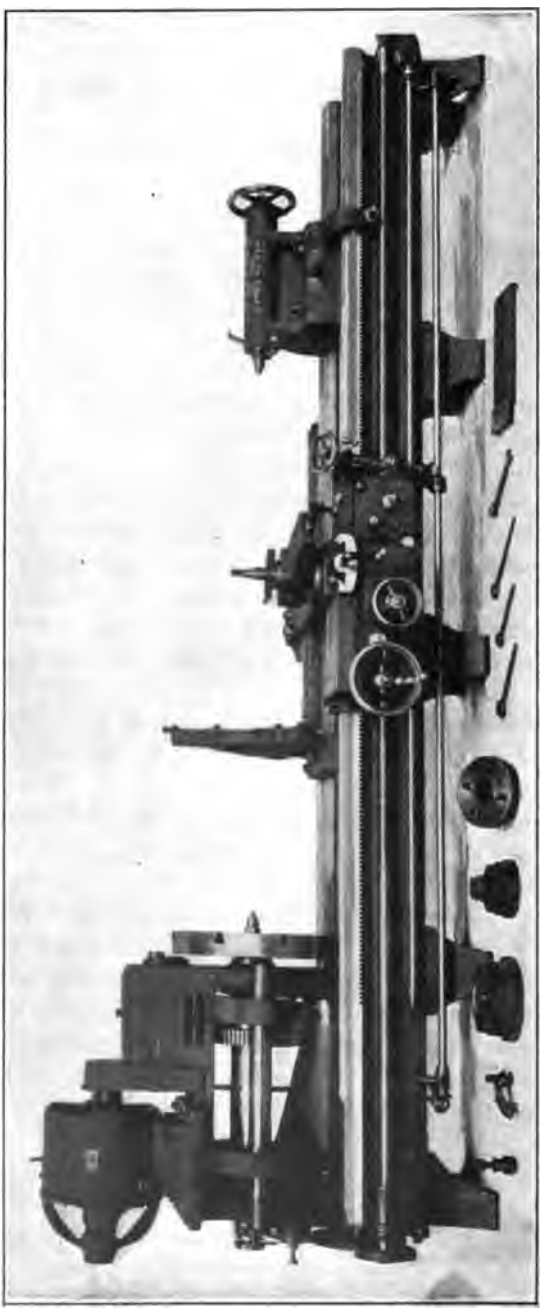


FIG. 40 APPLICATION OF ARMATURE-SHIFTING MOTOR TO A LATHE

mately become the standard for all classes, nor does it lend itself entirely to current designs.

The choice of the proper speed ratio for an adjustable-speed motor resolves itself into a very careful study of the ratios of the different gear changes for which the tool is arranged. In the case of engine lathes a motor of 1:3 or even 1:2 speed ratio is usually wholly satisfactory, due to the fact that more attention has probably been given to the application of motors to lathes than to any other tool, and in the designs of motor-driven lathes there are always a sufficient number of gear changes so that the jump in speed between gear changes is rarely more than 200 per cent and is therefore completely covered by an adjustable-speed motor of 1:3 speed ratio. This also applies to millers, radial drills, boring mills, etc., with double instead of single back gears.

There are, however, a large number of tools, including many millers, boring mills, radial drills, drill presses, shapers, etc., which when belt-driven have merely a cone pulley and a single back gear. When an adjustable-speed motor is applied to such a tool, as a rule it merely takes the place of the cone pulley and no change is made in the back-gear ratio, which is seldom less than 1:4 and is in many cases greater than 1:6. In consequence, there are many tools on which the use of motors with 1:4, 1:5, or 1:6 speed ratios is not only wholly practical, but is more economical from an operating standpoint in all cases where accurate speed control is in any way essential. Unless a motor is used whose range of speeds has the same ratio as the back gear, there will be a jump or gap of greater or less magnitude right in the center of the entire range of spindle speeds. It seems illogical to provide close speed adjustment over part of the range and not to provide it over all.

Take a tool with eight spindle speeds in geometrical progression from 20 to 320 r.p.m., obtained with a four-step cone pulley and a single back gear. Without going into the theory of geometrical series, the ratio from the first to the fifth speed in this series is practically 1:5. This fixes the ratio of the back gear for the cone-pulley type of tool. If a 1:3 motor is used with this same back gear, the speeds obtained are 20 to 60 r.p.m. with the back gear in, and 100 to 300 r.p.m. without the back gear, leaving a jump of 67 per cent between the two series. As speeds below 40 r.p.m. and above 200 r.p.m. are probably not used more than 10 per cent of the time, this means an important break in the center of the active range. This jump may not look very serious with a 1:5 back-gear ratio, but in many cases the ratio is 1:6, meaning a jump of 100 per cent.

In this same case a 1:5 motor would give speeds from 64 r.p.m. with the back gear in, and from 64 to 320 r.p.m. wi leaving no jump or break in the entire range. A still more satisf arrangement would be obtained if the tool manufacturer ch the ratio of his back gear from 1:5 to 1:4 when furnishing his sta

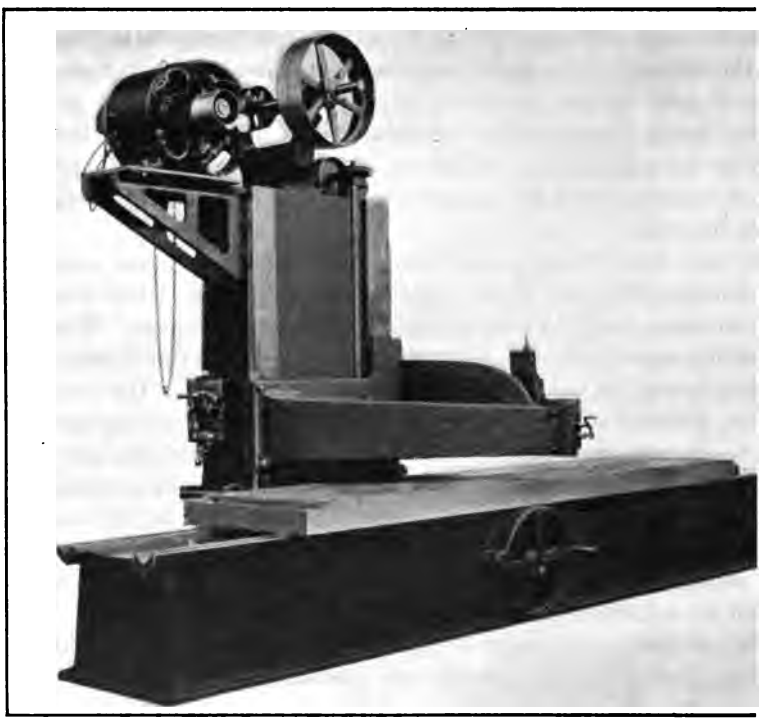


FIG. 41 ARMATURE-SHIFTING MOTOR APPLIED TO A PLANER

tool with motor drive. If this is done, a motor with 1:4 speed is just as satisfactory as the 1:5 motor, gives an unbroken ra spindle speeds, and is less expensive. The range of spindle speed becomes 20 to 80 r.p.m. with the back gear and 80 to 320 without.

I would not make this criticism if the machine tool ma turer made a practice of changing the ratio of his back gear wh nishing certain standard belt-driven types of tools equipped for by an adjustable-speed motor. There are many tools with

back gears whose total range of speeds is 1:16 or slightly greater and to which the addition of a second gear change for motor drive would add unwarranted expense. In most cases a change in the ratio of the back gear would add practically no expense, would simply mean a few additional stock gears for the manufacturer, and would make a motor-driven unit which is much more satisfactory to the purchaser. A motor with at least a 1:4 speed ratio should be used on these tools.

A motor of at least 1:4 speed ratio is also desirable on any variable-speed tool which, when belt-driven, is provided with no back gears. Slotters and some types of bolt machinery come in this class.

On certain specialized tools a consecutive range of spindle speeds with graduations not exceeding 5 per cent is not always necessary. Take for instance a driving-wheel lathe, used almost exclusively on two diameters of work, the outer tire and the finished spots on the axle for the bearings. A single back gear, taking into account the difference in the diameter of the axle and tire, as well as the difference in the materials of which these are made, and a motor of 1:2 speed ratio would be wholly satisfactory, even though this left a break of over 200 per cent in the center of the entire range of spindle speeds.

Applying Motors to Old Belt-Driven Tools. Another field for a motor of at least 1:4 speed ratio is in conversion to motor drive of old belt-driven tools. The majority of these have merely single back gears and the ratio is rarely less than 1:6. In changing many such tools for motor drive, especially the smaller and medium-sized machines, it is not only simpler but in many cases less expensive to use a wide-range motor rather than to install additional gear changes.

Types of Adjustable-Speed Direct-Current Motors. There are two distinct types of adjustable-speed direct-current motors used for machine tool work, both operating on the same final principle, namely, the increase in speed of a direct-current motor with any decrease in the strength of the magnetic field within which the armature rotates. In one type the strength of the magnetic field is varied by the use of resistance in the field circuit, and in the other the magnetic reluctance of the magnetic circuit is changed by sliding a slightly cone-shaped armature laterally away from its normal position directly beneath the main poles.

The characteristics and advantages of the armature-shifting type of motor for machine tool work are briefly as follows:

a No resistance controller is required. The speed cont mechanical, obtained by turning a hand wheel, an ation with which the machinist is thoroughly fan This hand wheel can be located at any point conve to the operator.

FIG. 42 DRILL PRESS DRIVEN BY AN ARMATURE-SHIFTING MOTO

b The speed control is a distinct and separate operation the starting, stopping or reversing of the motor. advantages are derived from this: (1) automatic starters can be used, taking entirely away from machine-tool operator all electrical control of the n and all possibility of abuse to motors, starting equip or controllers; (2) when the speed is once set, the n can be started and stopped as often as is necessa

caliper work or sharpen tools without affecting the speed-setting. In the case of unskilled operators, the speed can be set by a speed boss and cannot be tampered with.

c A continuous speed-change is obtained instead of jumping by steps.

d The field distortion due to full-load armature current is practically no greater at high speed under weak magnetic field than at low speed under full magnetic field, due to the fact that under decreasing magnetic field the magneto-motive-force remains constant, the air-gap length is increased and the air-gap area decreased. Satisfactory commutation is therefore obtained over wide speed ranges and is still further augmented for heavy overloads by the use of interpoles.

e Wide speed ranges are secured without excessive cost. These are very often found valuable in applying adjustable-speed motors to machine tools having single back gears, or in converting to motor drive old belt-driven tools.

Methods of Applying Armature-Shifting Motors. The convenience of speed control with a field-resistance drum-type controller has been well illustrated and is always important from an operating standpoint. Equal convenience can also be obtained in the arrangement of the mechanical speed control of the armature-shifting type of adjustable-speed motor. Fig. 40 shows a 30 in. by 24 ft. engine lathe with the mechanical speed control operated from the crank handle at the right of the lathe apron, the connection to the motor being obtained by means of a splined shaft running along the lathe bed. A second splined shaft operated by a hand wheel, also at the lathe apron, controls the full-reverse drum-type starter seen on the right at the end of the lathe bed. The two operations are therefore separate but are both controlled from the same point. Fig. 41 shows a satisfactory and convenient method of controlling the speed where the motor is mounted high on the machine tool. This is done by means of a pendent chain similar to that used on chain hoists. Fig. 42 shows a high-speed drill press with the hand wheel for mechanical speed control brought to a point within easy reach of the operator at all times.

Conclusion. No one type of drive entirely meets all the varying conditions which are found in machine-tool operations. There are many cases where I would recommend belt drive or speed-box drive

with either group or individual constant-speed motors. Other conditions require adjustable-speed direct-current motors with field-resistance control, while in many others the mechanical speed control obtained with the armature-shifting type adjustable-speed motor offers advantages which cannot be obtained with any other method of machine tool drive.

The authors desired to present no closures.—EDITOR.

No. 1277

THE TESTING OF WATER WHEELS AFTER INSTALLATION

By Prof. C. M. Allen, Worcester, Mass.

Member of the Society

In the last few years there has been a growing demand for brake tests of water wheels after installation, the object being to determine the horsepower and in many cases the efficiency of the wheels, under actual running conditions, as well as to ascertain whether the wheels are up to their guaranteed rating.

2 The Holyoke testing flume is the only place in the United States where commercial tests of water wheels are made. For purposes of comparison under similar conditions, these tests serve their purpose well and their influence has been great in the development of the modern efficient turbine; but however well a wheel may show up under a test so made, it may or may not give equally good results after installation. That depends entirely upon the kind of wheel, conditions of setting, and requirements of performance.

3 If the wheel is given a good setting and is allowed to run at the proper speed under a head suited to the design, then it will perform its rated work, which can be accurately computed from the original tests made at Holyoke, provided the wheel is not too large for the testing flume. This flume was not designed to test the largest of our modern turbines, nor is it suitable for testing high-head turbines. If the wheel is not given a fair setting and is required to run at too high a speed (which seems to be almost universal practice), it will fall down on both power and efficiency, the drop in each depending upon the departure from the normal conditions.

4 The efficiency of water wheels under actual working conditions has a very direct bearing upon the conservation of natural resources, and every inducement should be offered to keep that efficiency high.

Presented at the Boston meeting, April 1910, of The American Society of Mechanical Engineers.

If by increasing the efficiency, even by a small percentage, we are able to get more power from the same amount of water used, this clearly has a direct bearing on the question of conservation.

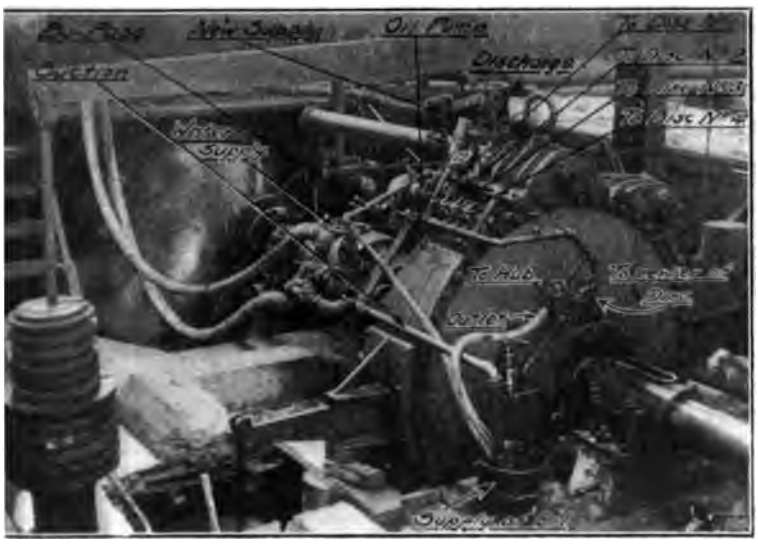
5 The water wheel as it is leads all other prime movers in efficiency. It has at least three times as good an efficiency as the steam engine, gas engine or steam turbine under ideal working conditions. There is, however, an important difference between coal and water considered as sources of power, namely, that if water is not used for power and used efficiently, then that power is lost forever. It is a case of use or lose. The coal not mined or used still remains for the years to come, but the water power not used at all or not used efficiently is gone. "The mill will never grind again with the water that is past."

6 There are many plants operated by water turbines that are from 10 to 15 per cent lower in efficiency than they might have been, had the proper kind of installation and setting been definitely known and used. It is, therefore, the desirability of determining the proper setting of the turbine, and the best speed of operation under actual running conditions, that has created, in a large measure, the demand for brake testing after installation.

7 The importance of having a water power developed and operated with maximum efficiency needs no argument; yet of the several reasons that may be mentioned, one of the most important, though apparently not always considered, is purely financial. In the case of several typical hydro-electric installations, for instance, the cost of power house, dam, reservoirs, generators, transmission lines, etc., is over 90 per cent of the total, leaving less than 10 per cent for the wheels; but upon the performance of the wheels, depends to a large extent the income from the entire installation. Any increase in the efficiency of these wheels means a direct gain in the power output, and this means, or should mean, not only bigger dividends but also a probable saving of coal somewhere. Wheels have been tested in the last few years in several plants where the difference between the guaranteed efficiency which should have been obtained, and the actual efficiency due to poor settings, was enough to make the difference between a good paying investment and one that did not pay at all.

8 When wheels are installed in hydro-electric stations, and apparently do not show the power and efficiency guaranteed, the question naturally arises, why should a brake test be thought necessary? This may be answered in several ways. In the author's opinion, an

ectrical test properly conducted should be sufficiently accurate and liable in determining the output of the wheels. The reason for aking a good many brake tests in the past has been to settle dis-ıtes between the hydraulic power and the electrical interests, rela-ve to the guaranteed operation of the plant. The majority of water ieel builders in this country are not willing to abide by the results an electrical test unless the wheels show up to the guaranteed power such tests. The generator manufacturers are also unwilling to ıume that the generators are low in efficiency, or that their testing ıaratus is unreliable. The use of the brake for actually determin-



1 60-IN. FOUR-DISC DYNAMOMETER; CAPACITY 3000 H.P. AT 200 R.P.M.

the horsepower-output of the wheels at the generator coupling is isfactory to all parties concerned, for the simple reason that the paratus is very much less complicated and more easily understood. ıreover, the accuracy of the brake can be determined on the ground ile under test, as the calibration of the machine can be made at at time, and there is no possible chance for a serious error. In other ırds, the brake test is the simplest, most accurate, and most direct ethod of measuring power, and is universally recognized as the andard.

9 In making electrical tests there are many more chances r errors to creep in than in making the brake tests. Ordinarily

several electrical instruments are needed which should be carefully calibrated before and after tests. These are liable to become change in transit to the station. Many times they are used under differen conditions of temperature, of magnetism, of connection, etc., tha when calibrated, and the total results are liable to error on accoun of the number of instruments to be read, thus bringing in error which may be more or less cumulative.

10 There is another reason for making brake tests rather tha electrical tests at the present time, which is purely a human one It is that no one but an electrical engineer, or some one with consider

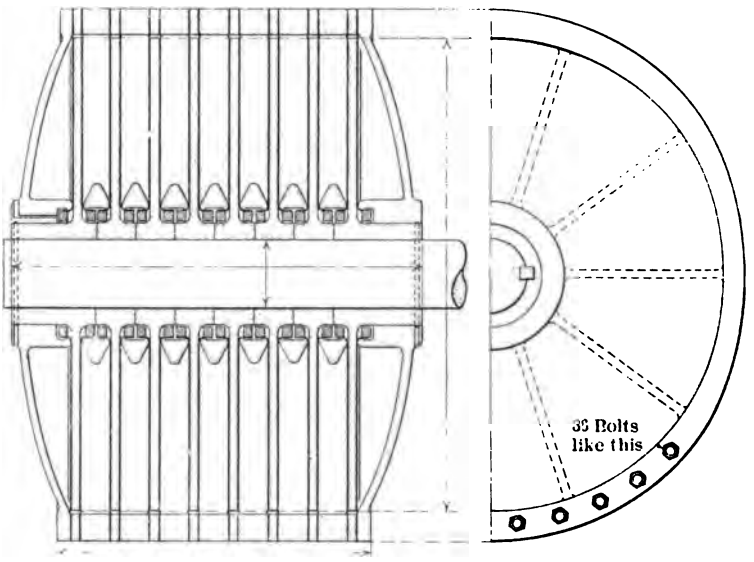


FIG. 2 ASSEMBLY DRAWING OF 28-in. ALDEN ABSORPTION DYNAMOMETE CAPACITY 2000 H.P., 1800 R.P.M.; EIGHT DISCS

able electrical engineering training, can understand the meth used on a complete electrical test, while everyone interested in th plant can understand the method of the mechanical brake tes All parties interested can have their representatives on the groun to check up all the measurements on the brake and calibrate th dynamometer exactly as it is used under running conditions, and get with certainty the output of the wheels which is to be deliver to the generator. Furthermore, in order to determine the comple characteristics of the wheels under varying gate openings, and wi any considerable variation in speed, it is not always practical to u an electrical generator to furnish the load.

It was with the idea of meeting this demand that the Alden
rption dynamometer has been developed and built in large sizes.
principle of the dynamometer is so familiar that only a brief
ription will be given. It is a form of Prony brake, and usually
ists of several smooth circular revolvable cast-iron discs (see
2), keyed to the shaft which transmits the power; a non-revolv-
housing having its bearings upon the hubs of the revolving discs;
a pair of thin copper plates in contact with each cast-iron disc,
plates being integral with the housing. Through a system of
ıg, water under pressure is circulated through chambers between
nits, each consisting of a disc and its copper plates, and between

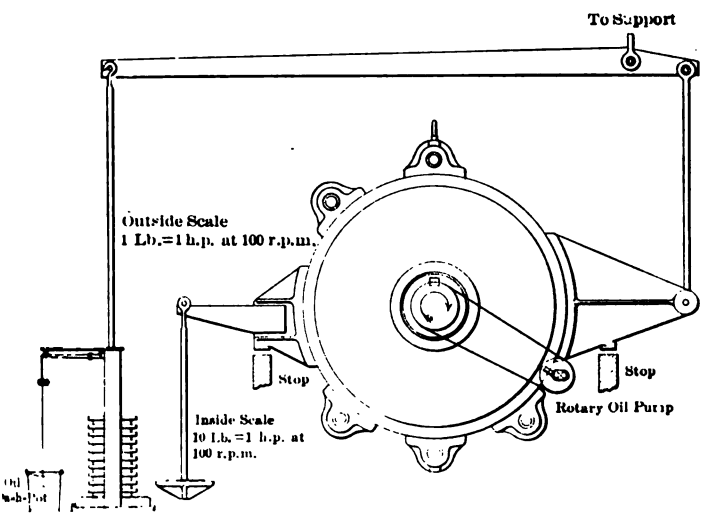


FIG. 3 SKETCH OF DYNAMOMETER SHOWING WORKING PRINCIPLES

ıuter plate at either end and the wall of the housing. The water
sure is regulated by hand or by an automatic valve. Another
m of piping circulates oil for lubricating the surface of the copper
s next to the revolving discs. In the large-sized machines, oil
pelled by a belt-driven pump mounted on the housing, enters the
ibers at the circumference and is forced along the radial grooves
e discs to the hub, and completes its circuit through hose connec-
s to the pump.

The power required to drive the pump is measured with, and
ded in, the power of the dynamometer, for the pump is bolted
he housing, and the driving tension in the belt which operates

the pump tends to rotate the housing in the same manner as does the internal friction of the discs; this makes a calibration to determine power used by the oil pump unnecessary (see Fig. 3).

13 When the dynamometer is in use, water passes through the chambers of the housing and between the several units of plates and discs, and by its pressure tends to force the plates against the sides of the revolving discs. This pressure increases the friction between the discs and plates, and this friction offers resistance to the rotation of the discs. The construction resembles that of a constantly slipping friction disc clutch. The resistance to turning imposed by the friction plates and discs is balanced by the weighing apparatus.

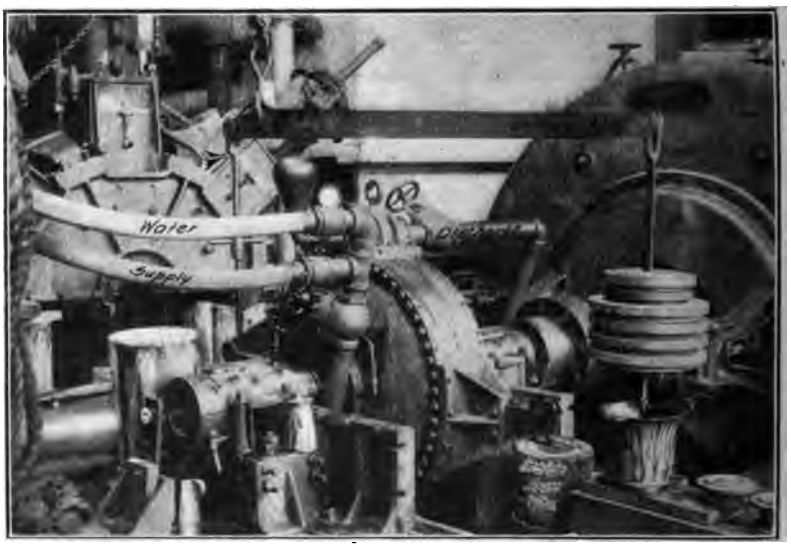


FIG. 4 METHOD OF COUNTERBALANCING UNDER LOAD

14 The power transmitted from the wheel under test tends to rotate the housing. This tendency is counteracted by the dead weights or platform scales, and the housing is kept from rotating, beyond prescribed limits, by stops on either side of a lever arm bolted to the housing. The weighing apparatus by which the power absorbed is measured is delicately adjusted on knife-edge bearings. There are two sets of lever scales, which may be called the outside and inside scales. The outside indicates 1 h.p. for 1 lb. weight per 100 r.p.m. The inside scale indicates 1 h.p. for 10 lb. weight per 100 r.p.m. The outside scale serves not only to assist in balancing

he load—that is, to weigh it—but also to take the weight of the ousings from the bearings on the hub of the revolving discs (see ig. 3 and Fig. 5).

15 It is possible to take from the bearings not only the weight of he dynamometer, but also the weight of the shaft. There have ecently been made several tests on wheels developing over 2000 h.p., here the entire weight of the dynamometer and shaft (about 13,000). total) was counterbalanced so nicely that the nearest required nning bearing was that of the water wheel some seven feet away om the dynamometer. In other words, when the load was on the

FIG. 5 AUXILIARY METHOD OF COUNTERWEIGHTING UNDER LOAD

lynamometer, it was as if it were placed on an overhanging shaft about seven feet from the nearest bearing. This point is an interesting one in mechanics, and shows that the wheels tested in place can be given a fair treatment under test, in that no additional load due to the weight of the dynamometer is put upon the wheel bearings.

16 To calibrate the dynamometer requires simply the determination of the distance from the center of the shaft to the knife edge bearing of the lever rod, and the ratio of the overhead lever; and the standardization of the dead weight, if used directly, or of the platform scales. Besides this, it is necessary to determine the initial load on

the dynamometer due to the unbalanced effect of the piping, fittings, arms, stops, lever and scale pan. This should be done at the time of test and with the apparatus as used. The usual method employed (shown in Fig. 7) consists in disconnecting the shaft coupling and raising the dynamometer so that parallel irons can be placed under the shaft; by means of a strut under the knife edge on the end of the lever the correct weight of the initial load is then obtained by the use of platform scales.

17 The largest dynamometer built at present consists of four 60-in. discs and has a power-absorbing capacity of 1500 h.p. at 100 r.p.m., or about 3000 h.p. at 200 r.p.m.

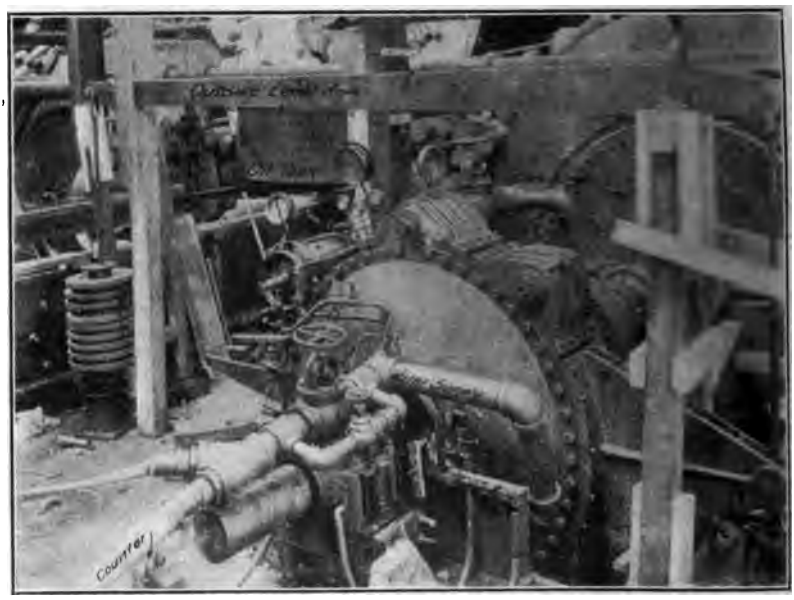


FIG. 6 DYNAMOMETER RIGGED FOR TESTING

18 The capacity of the dynamometer is limited by the amount of heat that can be transmitted through the copper plates. This depends upon the range of temperatures and the amount of the circulating cooling water. The capacity is also affected by the kind of lubricating oil used. A cheap grade of cylinder oil has been found satisfactory. A system of forced lubrication is essential to smooth operation.

19 A series of tests has recently been made at the laboratories of the Worcester Polytechnic Institute to determine the relative heat-transmitting properties of copper sheets just as they are received from the rolling mill, and similar sheets electro-copper-plated. These tests were made with a view to increasing the capacity of the dynamometer. The apparatus used consisted of two double-disc Alden dynamometers with the rotating cast-iron discs removed (see Fig. 8). The dynamometers as tested consisted of an outside cast-iron casing and four copper sheets, with the necessary spacing rings. The dynamometers were identical in every way, except that in one the copper sheets were electro-copper-plated.

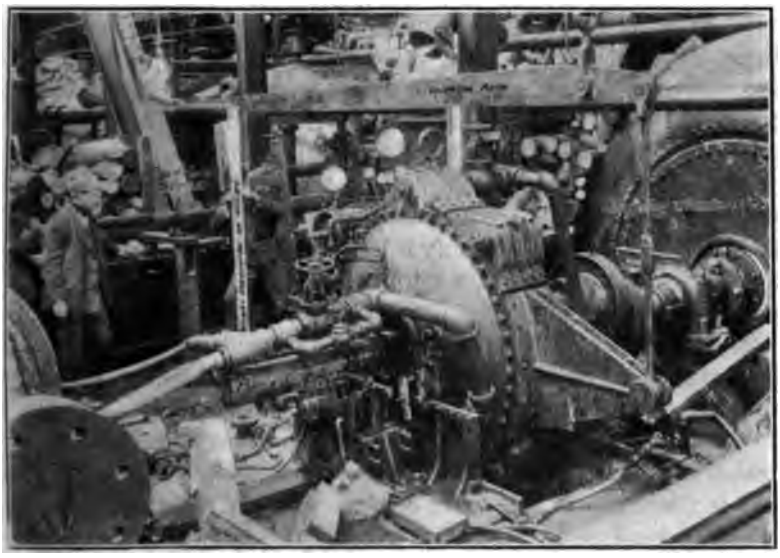


FIG. 7 METHOD OF CALIBRATION AFTER TESTS
COUPLING DISCONNECTED, SHAFT RESTING ON PARALLEL BARS, UNBALANCED LOAD OF DYNAMOMETER WEIGHED ON SCALES

20 The dynamometers were set up so that the spaces normally occupied by the revolving discs were piped to the steam main. Plugs were removed from the top and bottom of these spaces so that all air and condensed steam would be removed. Circulating water was supplied at the bottom of the casings and taken out at the top, both the circulating water and condensed steam being collected and weighed. Thermometers were inserted in the steam line next to the dynamometers and in the water supply line, also in the discharge of the circulating water and of the condensed steam. Several tests

were run on each, of five minutes' duration. Table 1 gives results of these tests.

TABLE 1 RESULTS OF TESTS

	Plain Copper Sheets	Electro-plated Copper Sheets
Average temperature of entering circulating water.	44 deg. fahr.	44 deg. fahr.
Average temperature of exhaust circulating water.	100 deg. fahr.	100 deg. fahr.
B.t.u. per sq. ft. per min. per 50 deg. difference in temperature of circulating water.....	467	610
Increase, in percentage.....	...	30.8

21 The results were all reduced to a common basis, namely: the B.t.u. transmitted through 1 sq. ft. of copper sheet per min. per 50 deg. difference in temperature of circulating water. The dynamometer containing the copper-plated sheets showed an increased heat transmission of more than 30 per cent over the untreated. A probable explanation of this phenomenon is that when the sheets are electro-copper-plated, the copper is deposited in small globules and the actual surface not only is increased but is made rougher; this tends to mix up the water currents, bringing more new water in contact with the copper.

22 In the actual operation of these dynamometers, the heat is generated on a thin film of oil directly against one side of the copper and the water passes over the surface on the other side, carrying off the heat generated. It is a well known fact that more heat is transmitted through copper than can be readily carried off by the water, and any increase in surface in contact with the water gives a corresponding increase in capacity. As the capacity of these dynamometers depends upon the heat-transmitting power of the copper sheets, it is clear that this capacity can be increased 30 per cent by the use of electro-plated sheets.

23 Owing to the system of continuous forced lubrication, the dynamometers are capable of holding their maximum load for any length of time. A dynamometer recently used held a load of from 2000 to 2300 h.p. during a series of tests on a pair of turbines of over eight hours' continuous running. The reason for making so long a run was that the weir for measuring the water used was situated in the canal above the turbines, and considerable time was required to allow conditions to become constant. It may be of interest to note that this weir was standard, with end contractions, and was

73 ft. long. During the tests, when the wheel gates were wide open, the quantity used by the wheels required a head of 2 ft. on the crest of this weir. Long runs are also required when the current meter is used in measuring the discharge from the wheels.

24 The largest power ever absorbed at one time by these dynamometers was 4100 h.p., developed by a pair of turbines under a head of 110 ft. at a speed of 225 r.p.m. These turbines were used to furnish power for a paper pulp mill. There were six grinders on either side of the turbines, making twelve in all. The grindstones nearest the turbines were removed, and two dynamometers put in their places.

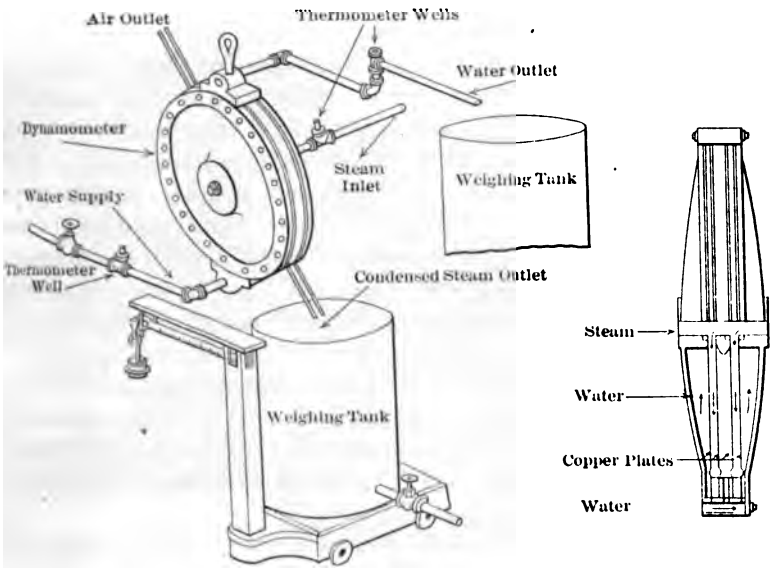


FIG. 8 LAYOUT OF APPARATUS; WITH SECTION OF DYNAMOMETER

25 The amount of work required to make such tests is comparatively small, when the amount of power measured is considered. Two units of approximately 4000 h.p. were tested inside of three days.

26 In pulp mills it is difficult to know how much power the wheels are developing. It is not always safe to base the estimate on quantity of pulp, as there are many variations in the conditions of stones, wood, etc. Hence quite a large percentage of brake testing of wheels has been done in grinder rooms.

27 Several tests of large powers have been made in hydro-electric stations in which case the generators are set aside and the dynamometer mounted on the wheel shaft, usually in place of the half coupling.

28 To give an idea of the actual running conditions sometimes found, a test in one plant showed that the wheels were giving the power called for by the contract, but that if they had been run at 200 instead of 225 r.p.m., the power would have been increased from 2000 to 2300 h.p.; thus showing a waste of 300 h.p. and a correspondingly lessened efficiency. On another test it was found, that when the wheels were running at the guaranteed speed, the power and efficiency were between 30 per cent and 40 per cent lower than they should have been. Removing the entire load only slightly increased the speed.

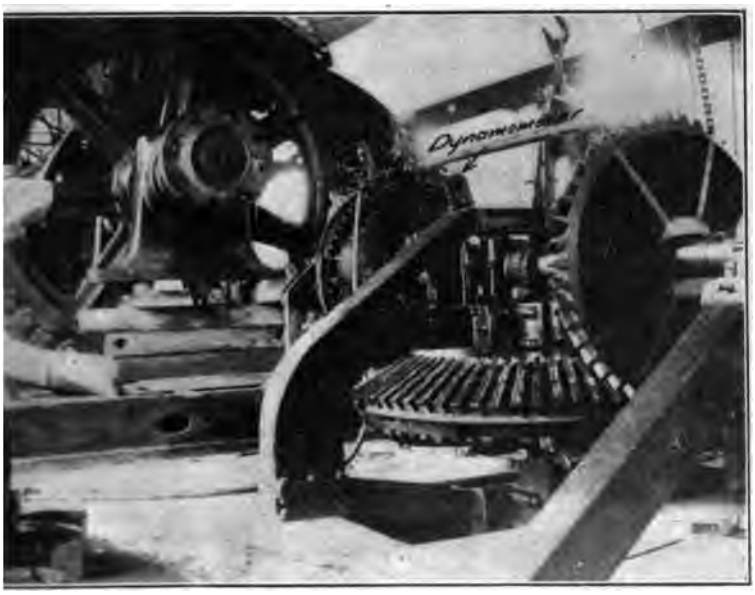
29 Many tests have been made which show that if the wheels are given a "fair setting," and the speed properly chosen, they will agree closely with the computed ratings made from the tests at the Holyoke flume. One test of a pair of wheels, made after installation, agreed so closely with the computed results from the Holyoke tests of the individual wheels, that the curves showing the relation of the horsepower and efficiency to the speed-gate opening of the pair came between the curves of the separate wheels transferred to the same head basis. The term "fair setting" means that the water should be brought to the wheel with a low velocity; the draft tube should be designed especially for the particular conditions, and should be air-tight; the wheels, if a pair, and center-discharging, should not be set too closely together; if a pair and outward-discharging, end supply should be avoided if a steel penstock is used; the shaft of the wheel should not be larger than necessary; the bearings should be kept in line, etc. The setting just described refers to open flumes or steel penstocks and not to spiral casings.

30 Incidental to the brake testing of water wheels, considerable information has been obtained regarding the efficiency of large bevel gears, such as are commonly used in transmitting power from vertical wheels in low-head installations. About a year ago, a series of tests were made to determine: first, the horsepower delivered to the horizontal generator shaft from two vertical wheels; second, the horsepower of the individual vertical wheels. By subtracting the former from the sum of the latter, the loss due to the bevel gears and bearings was obtained. The tests were conducted in the above order so as to get the output at the generator coupling with gears running normally. Then the gears were removed and the individual vertical tests made.

31 The total horsepower delivered to the generator was approximately 700 (see Fig. 9 and Fig. 10). The driving gear was of the

nary wood-mortise type, outside diameter 6 ft. 5 in. approxi-
ely, with 68 teeth, 14 in. wide, meshing with a cast-iron pinion
:h had 48 teeth with a planed tooth outline. At full load the
in the gears was 3.5 per cent and 3.4 per cent for two separate
s, or the efficiency of the horizontal-shaft vertical-wheel gear
e was about 96.5 per cent. The gears were well lubricated with
ick grease.

! About nine months later it was necessary to test one of these
e units in exactly the same manner. The loss in gears this time
a trifle less, the tests giving 3.1 per cent. As a matter of fact,



IG. 9 HORIZONTAL TESTING OF VERTICAL WHEELS WITH BEVEL GEARS

gears were running more smoothly at the last test, having had
e months more of service. When the first tests were made, the
nt had been running less than a year.

3 Besides this direct measurement of gear efficiencies, two sepa-
e tests have been made within the past year, of two vertical Boyden
eels with the power measurements made on the horizontal shaft.
ese wheels had been in operation for over thirty years. The
rel gears (both the driving and the driven) were of cast iron in
h unit. No brake tests were made on the vertical-wheel shafts but

the discharge from each was carefully measured over a standard weir by Mr. A. F. Sickman, hydraulic engineer for the Holyoke Water Power Company. The best efficiency of the wheels at full gate, which in this case includes the loss of gears and bearings, was 83.5 per cent and 83.7 per cent, respectively.

34 Several similar tests have been made with corresponding evidence as to good efficiency of the gears. In one plant, containing seven pairs of vertical wheels, where all the mortised wooden gears and cast-iron pinions had been in use for over fifteen years, these were still good, without having had even a tooth changed.

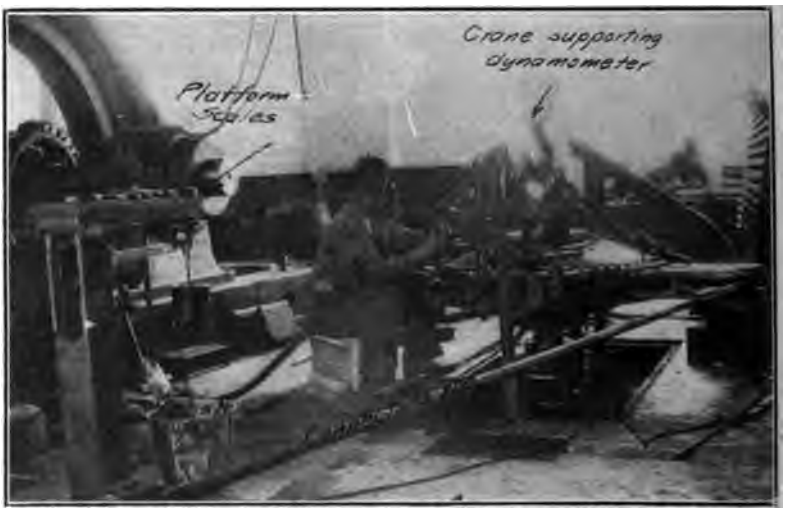


FIG. 10 TESTING OF VERTICAL WHEEL (GEAR REMOVED)

35 All of the information obtained concerning the loss due to bevel gear drives, leads the writer to conclude that if gears are properly designed, set up, and operated, and are not overloaded intermittently or continuously or left to care for themselves, they should show an efficiency of from 95 to 97 per cent.

36 Figs. 11 and 12 show two settings in which the wheels were tested after installation. The results of the tests, together with the results of the tests on the same wheels at the Holyoke testing flume, and reduced to a common head-basis, are given in the curves, Figs. 13 to 16 inclusive.

37 The setting shown in Fig. 11 is for a pair of 36-in. wheels operating under a head of 28 ft. at a speed of 200 r.p.m. The wheels are

et 3.3 diameters apart and the draft tube changes from a circular to an oval cross section with a constantly increasing area, and discharges horizontally into tail-race. In this particular installation, the velocity of the departing water from the draft tube was found to increase materially the working head on the wheels. The results of the brake tests made after installation, as shown by the accompanying curves, checked with the Holyoke tests computed for the same head at full gate. It may also be of interest to note that the generator tests made immediately following also checked with the brake tests. The difference between the two tests as shown in the curves at part gate openings is probably due to different methods of setting the gates under test. The full gate opening, however, was exactly alike in both cases.

38 In the setting shown in Fig. 12 the wheels actually give a considerable increase in power over that computed from the Holyoke tests. This is probably due to two reasons, the first and most important being that the Holyoke testing flume is not designed to test wheels of this size; and second, that the setting is exceptionally good. The wheels are 48 in. in diameter and are set 4.25 diameters apart with ample space around the wheels in the casing and with well-proportioned center case and draft tube. The curves in Fig. 15 and Fig. 16, representing the results of tests made on these wheels both at Holyoke and after installation, show that the best speed at full gate as computed from the Holyoke tests is about 182 r.p.m., and the best speed after installation 195 r.p.m. Comparison of the horsepowers at best speed shows an increase after installation of 40 h.p., but if the horsepowers at 195 r.p.m. be compared, then there is an increase of 130 h.p. This apparently excessive increase in power is to a large extent due to the fact that the best speed after installation was 195 r.p.m., while from the curve of the Holyoke test the power at 195 r.p.m. has materially dropped off.

39 The curves in Fig. 17 and Fig. 18 show the results of tests on a pair of 45-in. wheels under a head of 44 ft., with a normal speed of 200 r.p.m. It is seen that the discharge increases with the gate opening but the power begins to drop off at 0.75 gate opening and remains contant from 0.9 to full, which accounts for the efficiency curve dropping off so rapidly. In this installation the wheels were set too closely together (less than three diameters apart) and the shaft was excessively large. In accordance with data obtained from our recent tests these wheels should have been set at least four diameters apart.

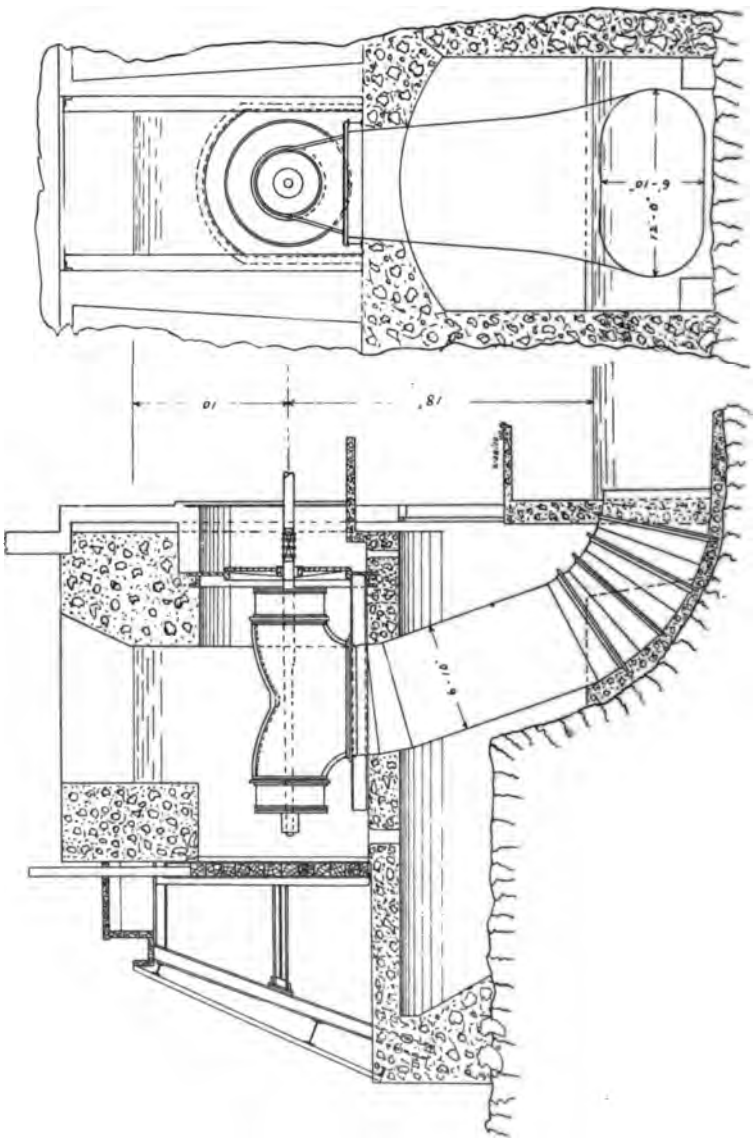


FIG. 11 SETTING OF A PAIR OF 36-IN. WHEELS UNDER 26-FT. HEAD. DISTANCE BETWEEN WHEELS 3.3 DIAMETERS

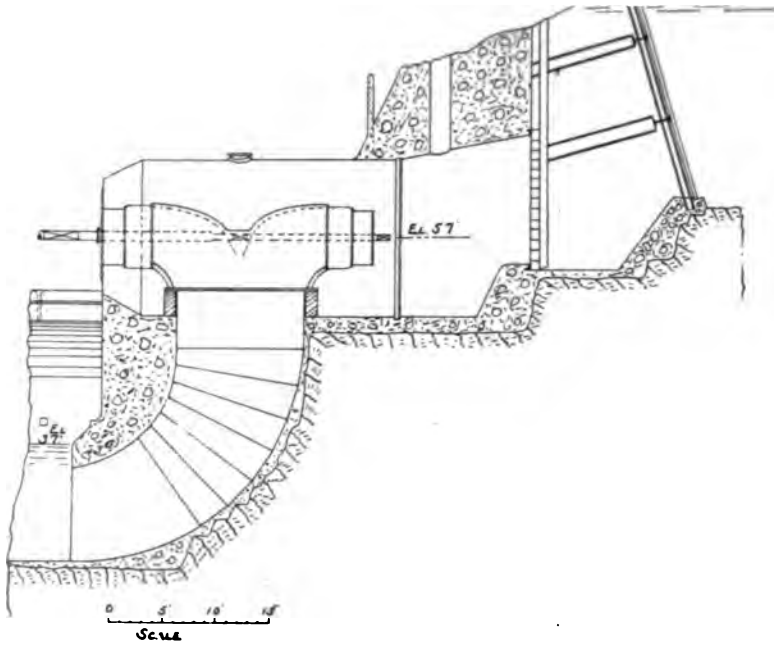


FIG. 12 SETTING OF A PAIR OF 48-IN. WHEELS UNDER 40-FT. HEAD. DISTANCE BETWEEN WHEELS 4.25 DIAMETERS

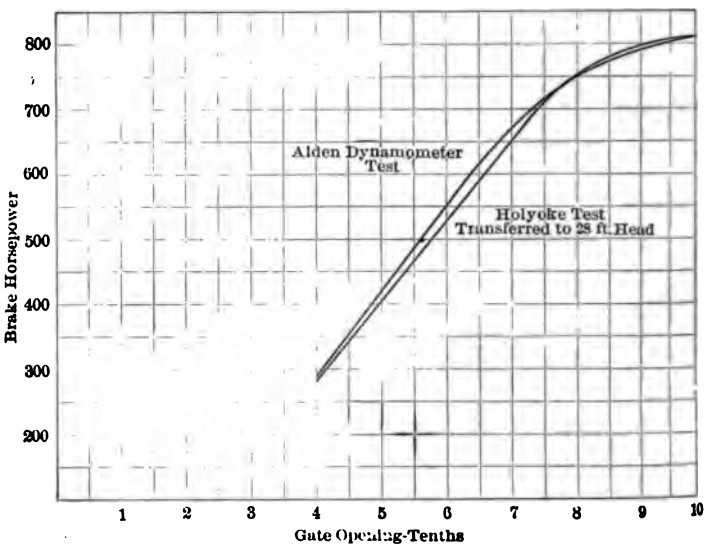


FIG. 13 CURVES SHOWING RELATION BETWEEN HORSEPOWER AND GATE OPENING FOR A PAIR OF 36-IN. WHEELS UNDER 28-FT. HEAD AND 200 R.P.M.

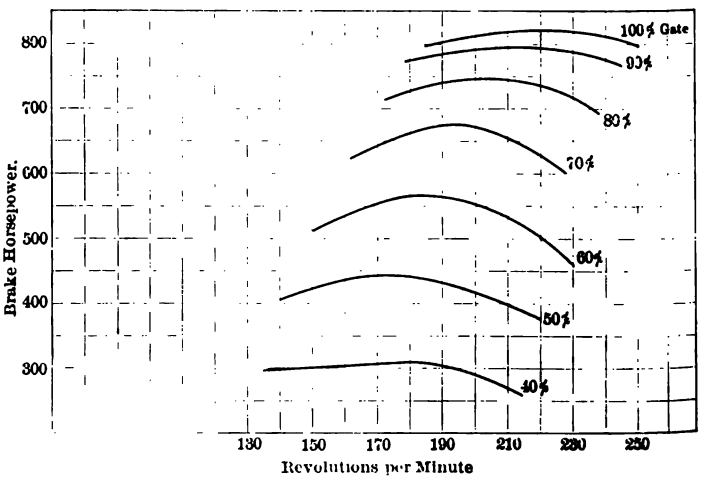


FIG. 14 CURVES SHOWING RELATION BETWEEN HORSEPOWER AND SPEED FOR A PAIR OF 36-IN. WHEELS UNDER 28-FT. HEAD

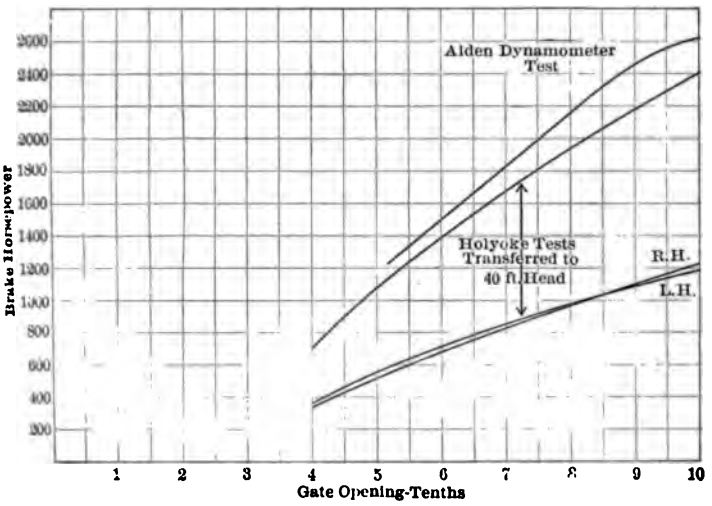


Fig. 15 Curves Showing Relation Between Horsepower and Gate Opening for a Pair of 48-in. Wheels under 40-ft. Head and 200 r.p.m.

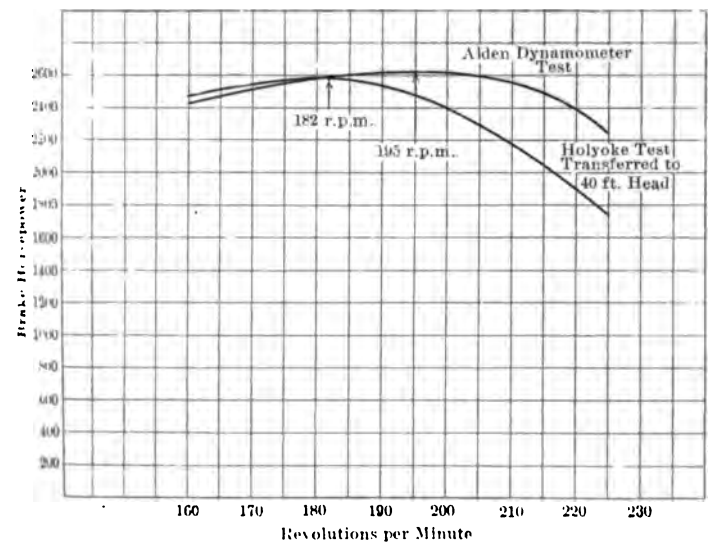


Fig. 16 Curves Showing Relation Between Horsepower and Speed at Full Gate For a Pair of 48-in. Wheels under 40-ft. Head.

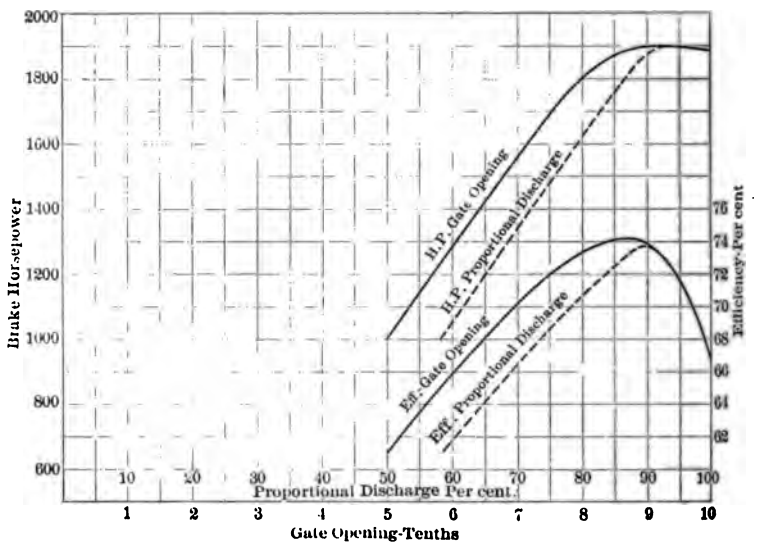


FIG. 17 CURVES SHOWING RELATION BETWEEN HORSEPOWER AND GATE OPENING, HORSEPOWER AND PROPORTIONAL DISCHARGE, EFFICIENCY AND GATE OPENING, EFFICIENCY AND PROPORTIONAL DISCHARGE; PAIR OF 45-IN. WHEELS, 44-FT. HEAD AND 200 R.P.M.

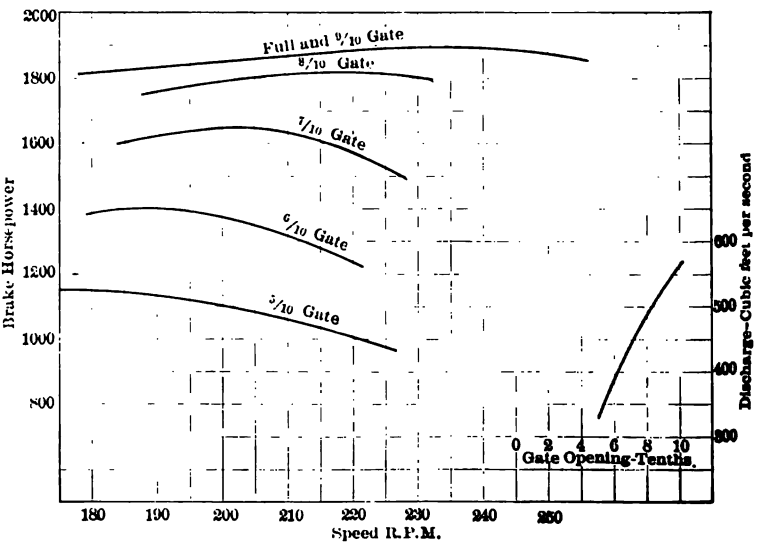


FIG. 18 CURVES SHOWING RELATION BETWEEN HORSEPOWER AND SPEED, GATE OPENING AND DISCHARGE; PAIR OF 45-IN. WHEELS, 44-FT. HEAD

40 While the tests on the 48-in. wheels shown in Fig. 12 are the best example that we have of large turbines actually showing more power when tested after installation than that computed from the Holyoke tests, it is by no means the only instance of such results. Within the past five years there have been made over 100 complete brake tests of wheels at different plants in all of the New England States and most of the Eastern Atlantic States. Most of the leading makes of wheels have been tested in this manner, and under heads varying from 10 ft. to 200 ft. Information derived from this experience confirms the following general statement:

41 That the performance of low-head turbines of diameters up to about 36 in., as computed from the Holyoke tests, should be attained after installation; that turbines greater than 36 in. in diameter should show better results after installation than those computed from the Holyoke tests, the amount of difference increasing with the diameter of the turbine.

42 There is still a vast deal of information needed concerning the behavior and proper settings of wheels after installation, before the subject can be put upon a good working basis, and it is hoped that enough points have been touched upon in this paper to call forth a goodly amount of discussion and reliable information that may be of value.

DISCUSSION

R. A. HALE.[1] The Holyoke testing flume has furnished much valuable information in regard to the efficiency of wheels, but it has always been apparent that differences in efficiency occur, depending on the conditions of installation. No absolute knowledge can be obtained without an actual test of the wheels in position to drive the mill. The example cited by Professor Allen of a pair of wheels placed so close together that the discharges interfere is common where space is limited and the quarter turns are crowded together at the expense of efficiency. Other undesirable conditions may exist, such as high velocity in the penstock and a small wheel case leading the water in a much disturbed condition to the wheel. Another fault sometimes occurs in not having sufficient space in the raceway or pit under the wheel for the discharge, causing obstruction and loss of power.

A most important and often-neglected point in connection with wheels is the proper design of the draft tubes connected with the

[1] Principal Assistant Engineer, Essex Water Power Co., Lawrence, Mass.

discharge. They are often placed in some available space without regard to its size or direction. With wheels set on a horizontal shaft, as is customary at the present time when possible, long tubes are necessary. Sometimes these are installed with a uniform diameter and set vertically so that the water striking downwards on the bottom of the pit has to turn a right angle to leave the wheel. Examples of this method exist in what are considered model mill plants.

The most efficient forms of draft tubes illustrated in Professor Allen's paper are those shown at an inclination and discharging in the direction of the current, with a gradually enlarging area of tube from the inlet to the outlet. The velocity of the water leaving the wheel outlets is necessarily very high and with the enlarging area the velocity may be reduced, with a decided gain in the head derived from the reduction in the velocity of the water leaving the outlet of the tube. The amount of inclination of the tube from the vertical must be considered, and one case comes to mind where the inclination is such that when the wheels are run at part gate a large percentage of the effect of the draft tube is lost, as shown by the reading of the vacuum gages at the center of shaft. At full-gate opening a loss exists, but is not so serious. The inclination of the draft tube to a vertical line through the center of the shaft in this particular case exceeded 60 deg., and was set to avoid removing considerable masonry. Although no fixed rule of inclination or curvature can be stated, it would appear from various cases noted that the inclination should not exceed 45 deg. and all abrupt changes in direction should be avoided. The outlet of the draft tube should be submerged sufficiently to prevent air from entering and destroying the vacuum and the elliptical form of outlet as indicated in Professor Allen's sketch provides area without the necessity of deeper excavation, which a cylindrical tube would require. At Lawrence a slight modification has been used to obtain additional area by building in a rectangular concrete outlet extending beyond the end of the draft tube. It has been the practice to ascertain the height of water as compared with the tail race and, when unreasonable loss is indicated, a leaky packing box or some similar condition is looked for. These gage readings would correspond to the indicator cards of an engine in regard to discovering losses.

Our theoretical knowledge of draft tubes, however, is very limited, and the necessity exists for a series of experiments embracing various forms and inclinations of draft tubes, which would give exact knowledge of the best form and the conditions in which they should

be used. A series of vacuum gages attached at various points on the tube, or a water column shown by a glass tube, the upper end connected with the draft tube and the lower end with the water in the tail races, would show what conditions exist in various portions of the tube. A series of experiments in connection with brake tests on a wheel at the same time would add much to the knowledge of the efficiency of wheels and draft tubes.

One other point that suggests itself is the importance of the relative velocity of the wheel, or the ratio of the velocity of a point on the circumference of a wheel, to the velocity due the head of water.

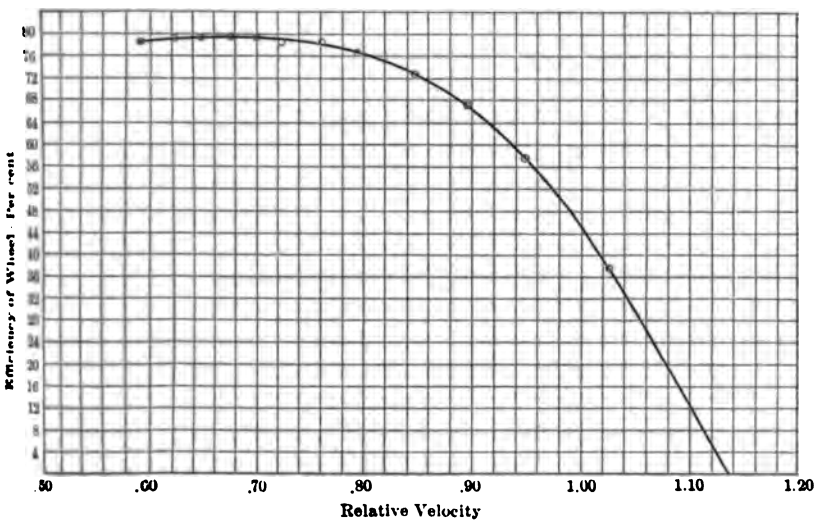


FIG. 19 VARIATION IN EFFICIENCY WITH RELATIVE VELOCITY

By reference to the curves given in Fig. 14, it will be noticed that there is a speed where the maximum power is obtained, and a falling off in each direction from this maximum. It is important, therefore, to select a wheel that shall run at the proper speed to give the maximum efficiency for the head under which it is to act. For this purpose the average head that exists most of the time would be selected. Under ordinary variations the percentage of loss is not excessive, but when great variations occur the efficiency is reduced materially with a constant speed.

Fig. 19 shows experiments made at the Holyoke testing flume on a 48-in. McCormack wheel, the horizontal scale representing the rela-

tive velocity and the vertical scale the efficiency of the wheel by the brake test. It will be observed that with relative velocities of from 60 to 75 per cent there is but slight variation in the efficiency. As the relative velocity increases beyond this point the efficiency falls rapidly. When at a relative velocity of 1.02 the efficiency is about 39 per cent, and at about 1.13 relative velocity there would be no efficiency. Such a curve is characteristic of this type of wheel.

Fig. 20, the practical application of this curve, shows the net horse-

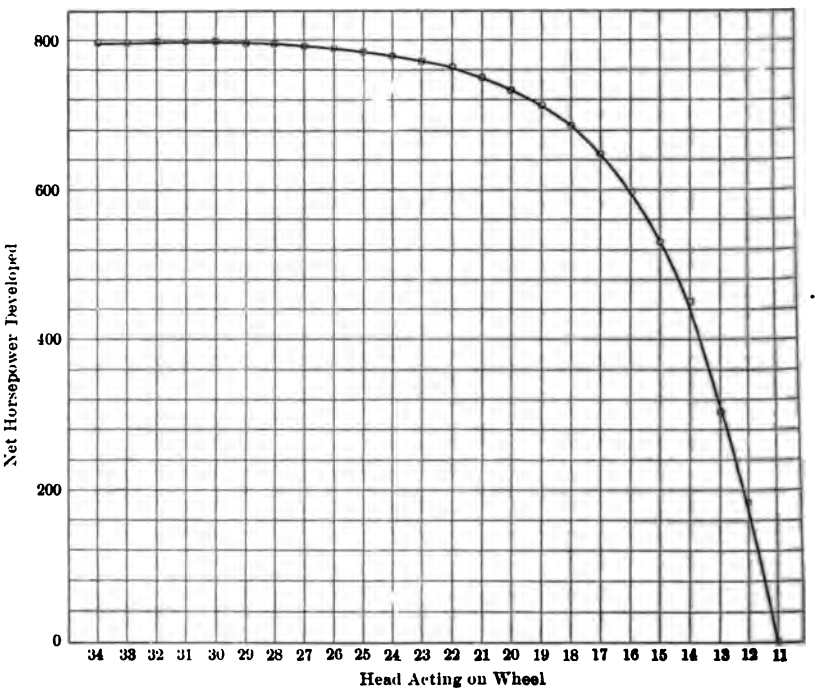


FIG. 20 VARIATION IN POWER DEVELOPED WITH CHANGE IN HEAD

power available from 1000 gross horsepower of water with heads from 34 ft. to 11 ft., assuming the speed of the wheel constant and the gate to the wheel wide open. The efficiency of the wheel is assumed as that given by the Holyoke test at full gate. With wheels designed for about 34 ft. the best results are obtained. With a decrease in fall to 20 ft. and the same speed, a falling off of about 50 h.p. occurs, and at 11 ft. there would be no power derived from the wheel. The conditions could not occur on one wheel as the quantity would de-

crease with decreased fall, but there would be a series of wheels added as the head decreases. Reduction of head due to freshets producing back water occurs on all streams, causing loss of power, even with a large quantity of water available.

The quantity of water is also affected by the speed of the wheel, and in computing tables of discharge this should be taken into account. The examples shown by Professor Allen of discoveries of loss of power by brake tests should be convincing proof that tests of this character are essential for actual information as to the efficiency of a wheel plant.

In connection with the two wheels set on a horizontal shaft and discharging into one draft tube, the results found by Professor Allen are very interesting. The discharge is affected to a considerable extent by the amount of opening of the wheel gates and whether or not both wheels are running. I have had occasion to measure the discharge from a pair of 36-in. Hercules wheels thus situated and at fifteen different gate openings on each wheel. The wheels were run together and then separately, and the combined discharge of the two wheels running together was considerably less than that obtained by adding the discharges when each ran separately. This showed that the confliction of the water discharged with both running reduced the amount that could be discharged. As wheels are run separately in this manner, it would appear that tests on this condition would be desirable.

In connection with the measurement of water very excellent results can be obtained under suitable conditions with the current meter. We have made various tests with the current meter, at the same time measuring the quantity of discharge over a weir under excellent conditions (quantities of 400 cu. ft. per second) with variations as low as 3 cu. ft. between the current meter and the weir. Excellent results have also been shown under conditions not as favorable. With the current meter attached to a pole instead of a line, correct results are more certain, and I should have entire confidence in the meter under the fair conditions which exist in flumes and raceways in connection with the discharge of wheels.

JOHN CASTLEREAGH PARKER. The Holyoke tests are very excellent for standardizing wheel practice, but they cannot in the nature of things give exact information as to what the wheel is going to do in the power plant. A great deal of the performance of a water wheel is dependent on the nature of the setting, the intake works

and the draft tube. Those are conditions which cannot be duplicated in any standard laboratory, which the Holyoke plant is in all essentials. The Holyoke flume is not, if I understand the construction of a testing plant aright, adapted to tests on wheels of special shapes. Most of the larger wheels of today are designed for use either as vertical-shaft or horizontal-shaft machines, with spiral casings. The Holyoke flume was designed for and is most applicable to the old barrel type casing. Practically all of the most modern wheels, in the larger sizes at least, are made with spiral casings. Field tests must be made if we wish to know what such wheels will do.

Another important value in the field tests is that they enable us to make checks from time to time on the performance of the wheels to find whether the runners are deteriorating.

Without intending to disparage the use of the dynamometer, I am inclined to question whether it should be designed as a substitute for electric loading. We recently tested three 16,000-h.p. turbines by the electric loading method, which we have found simple and easy to apply.

The electrical method provides a considerable degree of security from some of the vicissitudes that Professor Allen has spoken of in connection with his tests. When things go wrong it is simply necessary to close the gates without any worry as to what will happen to the dynamometer. The profession, however, owes a debt of gratitude to the man back of the development of a brake which will enable us determine the efficiency of turbines in those plants where the simpler electrical loading is not available. The paper industries require direct drive and a great many privately owned plants are used to operate manufacturing establishments, such as textile mills, for instance, where power is taken directly from the shafts of the turbines to the shafts in the building. In such cases it is convenient to have a simple and reliable method of getting the loading on the machines.

I want to express my accord with what Professor Allen has said in regard to the reacting effect of the design of housings and draft tubes on the efficiency of water wheels. The practice in this country and a great deal of the practice abroad has been vicious in the extreme, in that we have not attempted to put into the design of conduits, housings, and draft tubes even the most elementary hydraulic principles. American practice has lagged decidedly behind that on the other side in this respect. The old barrel type of housing is execrable, so far as developing efficiency is concerned, especially in the low-head

plants, where it has been used almost entirely. We are asking the water to turn at right angles, to change the velocity of flow in passing from sudden contractions to sudden expansions, and to do all sorts of things that no stream of water could readily do.

While field tests have no direct bearing on the design of runners, the tests at Holyoke and in the field, have helped to improve American runner design and have emphasized the importance of a construction adequate to lead the water up to and away from the runway. We are indebted to Professor Allen for what his tests will do in that direction and for bringing us to select our wheels more intelligently for the particular heads for which they are to run.

DWIGHT PORTER.[1] The most desirable test to apply to a turbine is one by which the input and output of power shall be accurately determined under the conditions of final installation. Professor Allen is rendering great service to users of power and to turbine builders by the work he is doing, and it should have generous recognition.

Of the three main factors underlying the question of turbine efficiency, namely, volume of water fed to turbine, head acting, and horsepower developed, it would seem that the latter two should generally be capable of determination with satisfactory accuracy. Under conditions which sometimes exist at a power station the measurement of the volume of water, however, may be open to material error, and the value of that error seems less easily assignable than at a standard testing station. The pair of wheels referred to in Par. 38 showed an increase of 130 h.p. at 195 r.p.m., when tested after installation, as compared with the amount computed on the bases of Holyoke tests made at a lower head. This means an increase of efficiency of between four and five per cent for the 2600 h.p. developed; but it is easy to conceive of circumstances in which an improper weir coefficient or an imperfect current-meter measurement might lead to an error of at least half that amount.

So long as the testing of wheels at a commercial station is common, where the head and conditions of setting are different from those under which the wheels are afterward installed, information of especial value will be afforded by tests such as those just cited, in which the same wheels are first tried out at the standard station

[1]Professor of Hydraulic Engineering, Massachusetts Institute of Technology, Boston, Mass.

and again after permanent installation. It is only by such comparisons that we may get sufficient light upon the error involved in computing from a Holyoke test the proper speed and probable output of the same wheel under a different head.

In making such computations it seems ordinarily to be assumed that the various losses of head from shock, friction, leakage and residual velocity will vary in the same ratio in which the gross head varies, and that consequently, the turbine efficiency will remain constant for the same gate opening and same relative speed; while as a further consequence the discharge will vary as the square root of the head. So far as theory goes, it indicates that these laws will approximately hold, but it can hardly be supposed that they will hold rigidly.

Even through a standard fixed orifice the discharge seems not to vary strictly as the square root of the head, but is affected by a changing coefficient which must be found experimentally. How, then, can the theoretic law be expected to hold exactly in the case of flow through a revolving wheel with its appurtenances of casing, guides, gate and draft tube. Draft-tube losses themselves are but little known and must be uncertain disturbing influences in many cases.

How much the common method of adjusting to a different head the results of a Holyoke test may be in error is only to be learned by comparisons such as Professor Allen carries out. Even though the error be but small in percentage, on large installations it may be a matter of much importance.

GEORGE E. RUSSELL.[1] One of the greatest stumbling blocks in the path of turbine development in this country has been the lack of systematic testing after installation. Errors in design have been made and perpetuated year after year, simply because purchaser and manufacturer have been satisfied to believe that turbines showing splendid results at Holyoke under a head of 18 ft. or less would give as creditable performances when used with heads five or ten times as great. That this was beyond the limits of reason we know now and should long since have known.

Under the low heads which were the first to be developed in this country, it was necessary to meet the demands for increased speed and power by decreasing the diameter and deepening the wheel axially. As the decrease in diameter prevented the free escape of

[1]Assistant Professor of Civil Engineering, Massachusetts Institute of Technology, Boston, Mass.

water from the radial inward-flow wheel of Francis, it became necessary to change the shape of the buckets in order to turn the water in them to an axial direction. Thus the Francis wheel was gradually metamorphosed into the vortex type. This wheel has been developed to a high degree under low heads by experimental testing at Holyoke and elsewhere. Very little, if any, of this class of work has been done under high heads, and there are enough reliable data to show that the general type of wheel so far produced in this country is not as efficient as designs from abroad which are based on the radial flow type. As to whether the vortex type can be brought to perfection under these conditions or not there appears to be some difference of opinion, and no intelligent answer to the question can be given until many reliable high-head tests are available. If the answer is to be favorable to the American turbine, then the attainment of this high efficiency can be possible only by development through experimental high-head testing. The shape of the American runner passage is so intricate as to defy mathematical analysis of the water's action, and in this respect at least the European design has much in its favor.

The wide and general continuance of the work so ably and carefully started by Professor Allen should be encouraged and advocated by all engineers interested in the highest possible achievements in water power development in this country.

H. K. BARROWS.[1] To improve the efficiency of turbines it is necessary to have an accurate determination of the quantity of water used by the wheel, as well as its power output. Even the standard weir, as it is usually installed under the conditions of a field test, is subject to errors of 2 or 3 per cent or more. Professor Allen showed a view of a large weir installed in a canal for such a purpose and it is evident that the expense of such construction would prevent its use in many cases. Then again, it is often undesirable to create such an obstruction to flow in a canal or tail race. Under such conditions resort must be had to some form of current meter to measure the discharge and the error in determination of flow may rise to 4 or 5 per cent. Except in unusual cases the field determination of efficiency cannot be made as closely as at Holyoke, and the Holyoke tests will always be valuable as a standard of water-wheel testing. When compared with field tests such as are made by Professor Allen, valuable conclusions can be drawn.

[1]Associate Professor of Hydraulic Engineering, Massachusetts Institute of Technology; and of Barrows & Breed, Consulting Engineers, Boston.

Complete field tests, including discharge and efficiency as well as power output, are desirable, not only to bring about improvement in wheel settings and connections but also to insure suitable conditions of water approach and discharge.

With some forethought it would be possible in many cases to arrange suitable conditions for current-meter measurements at little or no extra expense, either in the canal or tail race, and in an important water power development this feature of discharge measurements should certainly be kept in mind by the designing engineer. The necessary platform or supports for operating a meter could be provided for at slight cost. A well-designed wheel pit, draft tube, and tail race should afford hydraulic conditions suitable for current-meter discharge measurements.

The prevailing idea on the part of wheel users has heretofore been to secure the desired power, oftentimes at a great sacrifice of efficiency, and the testing of wheels in place and at Holyoke is doing much to bring this fact home.

HENRY D. JACKSON.[1] Many of the wheel manufacturers have gone to extreme pains to put their wheels into splendid condition for testing at Holyoke and the wheels have shown correspondingly excellent results, but these conditions would not last long, so that in actual practice the wheels would doubtless show quite different results from those obtained at Holyoke. This has led to the discrediting of the Holyoke tests by a considerable number of purchasers as well as by engineers, especially abroad. To what extent this discredit is well founded I am not prepared to say, but an examination of some of the catalogues, data for which were furnished from the Holyoke flume, leads me to believe that there is reason to question some of the Holyoke tests, particularly when used as they are by some manufacturers. It has been found by actual trial that wheels tested at Holyoke and then shipped elsewhere, for tests, particularly abroad, have shown very much lower results than at Holyoke.

As a rule, the purchaser of the wheel desires to know its efficiency under all conditions of load at a rated speed. The Holyoke tests, however, as quoted in catalogues, allow the wheel to assume its own best speed under each condition of gate opening, so that the speed neither remains constant nor holds a constant relation to the head. The tests are, therefore, subject to correction, which most purchasers

[1] Consulting Engineer, 88 Broad St., Boston, Mass.

are unable to make. The figures in Table 2, data for which are claimed to have come from the Holyoke testing flume, are quoted from the catalogue of a certain manufacturer, and an examination of a number of Holyoke tests discloses these same conditions.

TABLE 2 TESTS ON THREE SIZES OF WHEELS

	Gate Opening	Speed	Efficiency	Head
A	Full	194.25	81.08	15.29
	7/8	187.75	84.78	16.56
	3/4	178.50	83.88	17.33
	5/8	176.40	80.09	17.54
B	Full	144.00	82.03	15.00
	7/8	138.12	84.55	15.04
	3/4	127.67	83.68	15.11
	5/8	131.50	80.25	15.83
C	Full	109.00	83.58	13.27
	7/8	101.00	85.01	13.79
	3/4	100.00	81.06	14.69

The tests start as a rule with full gate and at a rated discharge and a number of runs are made with different loads and speed. Then the discharge is decreased and another series of runs made. If under full-gate opening the speed which corresponds to the rated discharge of the wheel is noted and attempts made to find under the different gate openings this same speed, it will as a rule be discovered that the speed decreases constantly with decreased gate. Rarely is the full-gate speed maintained or even quoted in the test results on the decreased gate openings.

Another reason for so much questioning of the Holyoke tests is the extremely high efficiencies which are sometimes quoted. For instance, a short time ago it was reported that a certain wheel showed approximately 94 per cent efficiency at the Holyoke flume. The theoretical efficiency of a water wheel would rarely exceed 97 per cent and theorists on water-wheel design claim the losses vary from 12 per cent upwards, so that such efficiencies seem to be very questionable, unless the theorists are mistaken in the value of the various losses. The wheel manufacturers do not as a rule guarantee their wheels at over 80 per cent efficiency and this would seem sufficient reason to believe that they themselves do not place too much reliance on the results obtained at Holyoke. There are times, however, when wheel manufacturers will guarantee considerable increases over 80 per cent.

But I am strongly inclined to believe, partly from experience, that they will balk when the purchaser asks that this guarantee be placed on paper, that the wheels be tested, and that a bonus and forfeiture clause be put into the contract. For these reasons, it seems to me decidedly advisable to test the wheels under conditions of installation, and the device used by Professor Allen appeals to me very strongly.

It is, however, open to some objections. Unless used with extreme care it would seem as though the results would be higher than the actual conditions of the installation should show. Suppose a generator be removed from the water-wheel shaft and a dynamometer be substituted. If the dynamometer be carefully balanced so that none of its weight is taken by the water-wheel bearings, is it certain that some of the weight of the water wheel is not removed from its bearings, thereby reducing the friction? In many cases the water wheel is fastened directly to a coupling on the generator shaft, so that the water-wheel bearing is also the bearing for the generator. At the same time, however, a large part of the friction on this bearing should properly be charged up against the water wheel, so that it is important in using this dynamometer to be sure that the bearing friction of the wheel is the same as it will be when the wheel is in actual service. This point being assured, the test, so far as the actual power delivered by the wheel is concerned, is a relatively simple matter. In case the water wheel is belted to lineshafting or any user of power, or in case it may be connected by gearing, the use of the dynamometer does not throw the same thrust on the bearings as exists where the wheel is actually doing its usual work; and as the power delivered by the wheel should take into account the losses in its bearings under conditions of actual service, it would seem to me as though the dynamometer test would show higher results than should reasonably be expected.

In making the tests certain errors exist outside of the dynamometer. These are in the measurement of the water and the measurement of the head acting on the wheel. The water in many cases may readily be measured by means of a weir and if the weir is properly proportioned the measurement may be quite accurate. It is seldom possible, however, to use a weir of standard dimensions and any change in the form will introduce errors of greater or less magnitude. The head acting on the wheel will be affected by conditions of setting, methods of getting water to and from the wheel, the shape of the penstock and draft tube, and the location of other wheels near that under test. On very high heads there is also a possibility of considerable error in determining the actual head working on the wheel.

I am glad to know that Professor Allen believes the test made by the use of the electric generator as a basis of measurement of the power delivered by the wheel is perfectly satisfactory. The efficiency of an electric generator can readily be calculated under practically all conditions of load and there should be no trouble in the use of the necessary instruments for determining the output of the machine. The effects of temperature or magnetism can readily be overcome and the error in the instruments to a large extent eliminated by the use of duplicates and care in handling the instruments in transportation and in service. The question of absorbing the power generated is a very different matter, as frequently it is difficult to design the apparatus necessary to absorb very large amounts of power without very great fluctuations. The water rheostat, while valuable in service, is not always easily controlled; nor is it always easy to vary the load of a generator over sufficiently wide ranges and speeds to give all of the characteristics of the water wheel which may be desired. These characteristics, however, are of service only to the investigator and the designer of the wheel and are not strictly for the purpose of determining whether the wheel is or is not up to its guarantee.

One of the great advantages in the use of the generator as a method of testing is that it is a permanent part of the installation, available for tests at all times, thus enabling the owner to check up the efficiency of the wheel and the conditions of installation and to determine whether or not anything has arisen to reduce this efficiency, or whether changes in the plant have in any way affected it. This is sometimes an important consideration.

In conclusion I would like to ask if there are not chances for error in the calibration or measurement of the brake constants.

H. C. DAGGETT. At the present time there is probably no feature of a hydraulic plant about which there are so few definite data as in connection with draft tubes. One reason is that no testing flume exists today which is suitably arranged and designed for making tests of draft tubes of different sizes and shapes. When water wheels are tested in place certain results as to power and efficiency are obtained, but there is no means of knowing to what extent these results are due to the design of the draft tube. For example, a pair of water wheels may be tested in place with a certain kind of draft tube and may give good results, while another pair tested with another type of draft tube may give poor results, but we do not know that the difference in efficiency was entirely due to the difference in the design of the

draft tube. It may have been due partly to the draft tube, to the difference in the actual efficiency of the water-wheel runners, to the way in which the water enters the wheel case or flume, to the difference in the design of quarter-turn or center case, to the number and design of bearings, or to other details. In other words, the actual tests in place are so comparatively few, and the conditions apart from the design of draft tube are so seldom alike, that it is safe to say we seldom or never test two units of water wheels where all the conditions except the draft tube are the same.

Therefore, each designer of water wheels uses his own ideas as to the proper form of draft tube to be used in any particular installation. He is influenced, of course, by the conditions to be met and by his own personal experience. He may design a draft tube with a view to saving rock excavation or, in case of a renewal of water wheels, to avoid changing the old wheel pit. In the case of horizontal water wheels, he is often influenced by the necessity or desirability of placing the elevation of the wheel shaft above tail water in time of freshet. Oftentimes, however, he has the choice of several different designs of draft tube, and it is difficult for him to know just which particular design would give the most efficient result. Some writers on hydraulic subjects have given tables showing the length of draft tube which may be used with different diameters of tubes. These tables, however, are arbitrary and are simply one individual's idea in regard to that particular point. The writer believes it is true that, everything else being equal, a vertical, conical draft tube will give greater efficiency than one built to any curve or set at any angle with the vertical. On the other hand, a draft tube that leaves the water wheel vertically and discharges horizontally in the direction of discharge of the tail race eliminates loss of head in the wheel pit to a large extent, and in many cases the gain in head would no doubt offset the greater efficiency that might be obtained with the vertical tube. Lack of information on this point, however, makes it impossible for us to say in any given case which would be the more efficient design and how much more efficient. Again, by constructing a draft tube at an angle from the vertical oftentimes a certain amount of excavation can be avoided but it is impossible to say whether the loss in efficiency by so doing is compensated for by the saving in the cost of excavation.

Some engineers have maintained that a properly designed draft tube should have a certain fixed angle of flare, regardless of the length of tube, velocity in the tube, or other conditions. The writer has had access to certain experiments on small tubes, however, which indicate that the best angle of the tube depends on the length of the tube,

city of the water in the tube, and the head under which the heel is operating.

uld certainly be very desirable if a testing flume were avail- ere careful experiments could be made of the results obtained ferent designs of draft tubes, where at the same time all other ns could remain the same, showing that the difference in was entirely due to the difference in draft tube design. Such ould be invaluable and the writer hopes that arrangements made in the near future whereby such a testing flume may be- ailable for the use of engineers, users and builders of water

AUTHOR. In reply to Henry D. Jackson's question re- the chances for error in the calibration or measurement of ke constants, I would state that the horsepower can be ned just as accurately as it is possible to measure the dis- from the center of the shaft to the knife edge on the arm brake, a length of about 5 ft., and also the level lengths, and 140 in. respectively, combined with the accuracy of dised weighing scales and a direct-reading revolution coun- he initial load on the brake is readily determined at the making the test (Par. 16). The load on the shaft bearings r wheels can be duplicated when under test if the load be lirect weight. If it is caused by belting and is in a direction han vertical, it is more difficult to obtain. The actual loss one or two bearings is ordinarily a very small fraction of 1 t of the total power developed.

No. 1278

STRENGTH OF CAST-IRON PUNCH AND RIVETER FRAMES

By Prof. A. Lewis Jenkins, Cincinnati, O.

Member of the Society

ctual stress relations existing in a simple cast-iron beam when d to a load have been the object of many investigations con- by engineers during the past hundred years. These investi- consisted of numerous experiments and mathematical deduc- the determination of the elastic laws and physical constants l in the analysis of stresses in straight cast-iron beams, but did ıde the necessary deductions for the case of curved beams simi- ınch and riveter frames.

ıe object of this article is to determine experimentally the rela- ween the ultimate strength of curved cast-iron specimens simi- ınch and shear frames and the ultimate strength of the attached s and to compare the experimental results with those deter- y the various methods of analysis used in designing castings of ihape. In making this investigation many publications relat- ıe subject have been studied and the most important results, which are only of historical interest, are stated and discussed ppendix.

FACTOR OF SAFETY

has been contended that the ultimate strength of cast-iron parts is of no practical value since the working stress seldom 5000 lb. per sq. in., and as Hooke's law is sensibly true this limit the ordinary formulae for beams should apply air degree of accuracy. It is frequently desirable, however, the ultimate strength of such elements as punch frames in design the safety link which is supposed to break and save the ı case of an accident or overload.

ıted at the Spring Meeting, Atlantic City, 1910, of The American of Mechanical Engineers.

4 The ordinary formulae assume that the stress in a beam is directly proportional to the load and factors of safety based on the ultimate tensile strength of the material are the same as if based on the ultimate strength of the beam. This is not true, however, for cast iron because the stress is not directly proportional to the load. A beam 1 in. square and 12 in. between supports made of cast iron having an ultimate tensile strength of 20,000 lb. per sq. in. would support a load of 222 lb. midway between the supports with a factor of safety of 5 based on the ultimate tensile strength. Such a beam would probably fail, however, under a load in the middle of about 2000 lb., giving a factor of safety of 9 based on the breaking load of the beam. Hence, by using the ordinary beam formulae in designing straight cast-iron machine elements that are to be subjected to bending strains the actual working stress may be close to that desired, but the actual factor of safety based on the strength of the casting will be much greater than the same factor based on the tensile strength of the material.

Methods Employed in Making Tests

5 For many years engineers have recognized the value of experimental data on the strength of cast-iron beams and a considerable volume of literature on this subject is now available. There are, however, no published data on the strength of curved beams similar in shape to punch frames. The results of some experiments on the strength of crane hooks published in the October 7, 1909, issue of the American Machinist, seem to show that the Pearson-Andrews formula is true within the elastic limit for steel specimens of small throat depth. It will be noticed, however, that the value used for Poisson's ratio does not compare favorably with the values of this constant usually given for steel.

6 In view of the fact that there seems to be no rational method for determining the strength of curved cast-iron beams the writer believes that some experimental data on this subject may be of practical value and also serve as an incentive for further investigation by others.

7 Three forms of test specimens as shown in Figs. 1, 2 and 3 were used for these tests. These specimens were carefully designed with a view to having them of equal strength throughout, the calculations being based on the ordinary formulae for beams. To prevent any torsional moment due to eccentric loading the specimens were provided with two small hemispherical projections for receiving the load. A round and a rectangular test bar were cast with each specimen as

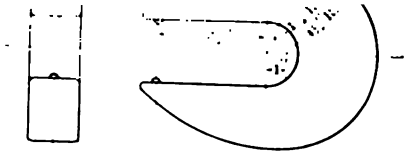


FIG. 1 DIMENSIONS OF SPECIMENS 1, 2 AND 3, PLATE I

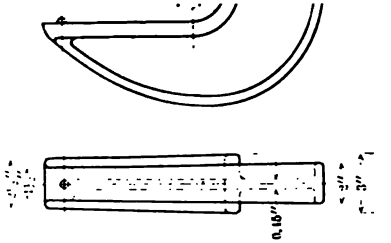


FIG. 2 DIMENSIONS OF SPECIMENS 4, 5, 7 AND 12, PLATES I AND II

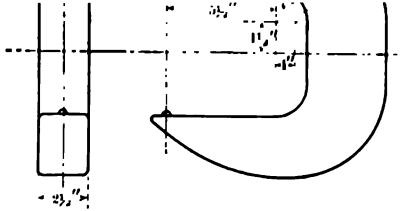


FIG. 3 DIMENSIONS OF SPECIMENS 16 AND 17, PLATE III

FIG. 4 ROUND AND RECTANGULAR TEST BARS CAST WITH EACH SPECIMEN

shown in Fig. 4. The castings were made by the Buckeye Foundry Company of Cincinnati and poured from a heat run to cast lathe beds.

8 The 100,000 lb. Riéhle testing machine shown in Fig. 5 was used for making the tests. Fig. 6 shows the method employed for applying the load. Two stirrups forged from 1 in. by 3 in. steel and then tem-

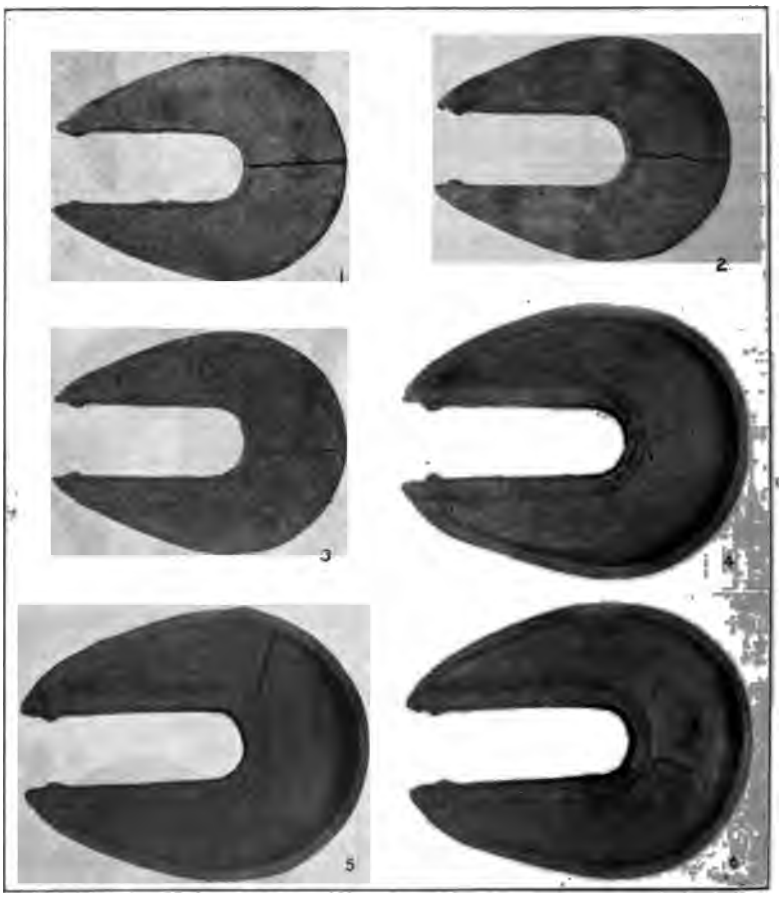


PLATE I CURVED CAST-IRON SPECIMENS BROKEN BY TESTS

pered were held in the grips and received the castings. The tangs of the autographic recorder were placed between the casting and the stirrups, thereby eliminating the deflection of the stirrups and the bearing projections on the castings.

SIZE OF SPECIMENS

lates I, II, and III were made from photographs of the broken ens. The dimensions of specimens No. 1, 2 and 3 are shown in and Fig. 2 shows the dimensions of specimens No. 4, 5, 7 and ne flanges on No. 12 were partially removed, but this did not

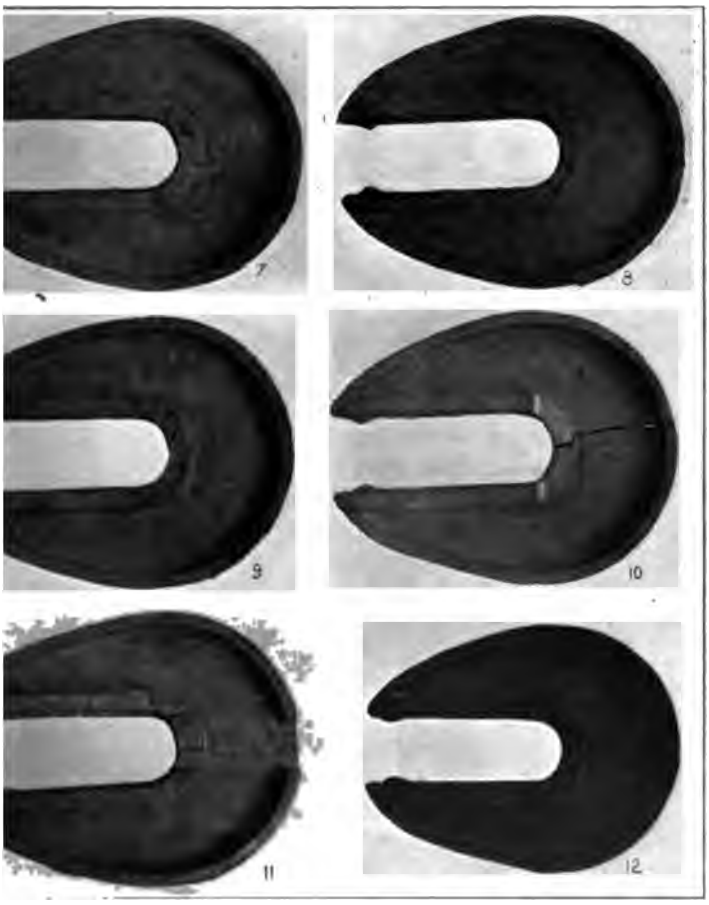


PLATE II CURVED CAST-IRON SPECIMENS BROKEN BY TESTS

ts strength. Specimens No. 9, 10, 11 and 13 were cast from the attern as No. 4 and the flanges altered as shown. No. 6 was om the same pattern as No. 4 after the thickness of the web had ncreased to 0.93 in. No. 14 differs from No. 6 in that the fillet the flange is larger. No. 15 is the same as No. 14 with the out-

side flange removed. Fig. 3 shows the dimensions of No. 16 and 17. No. 18 is the same as No. 16 with depth of spine reduced to 3.4 in.

RESULTS OF TESTS

10 Table 1 gives the results of the tests. The unit tensile strength of the test bars varied from 18,600 to 24,400 lb., and the flexural

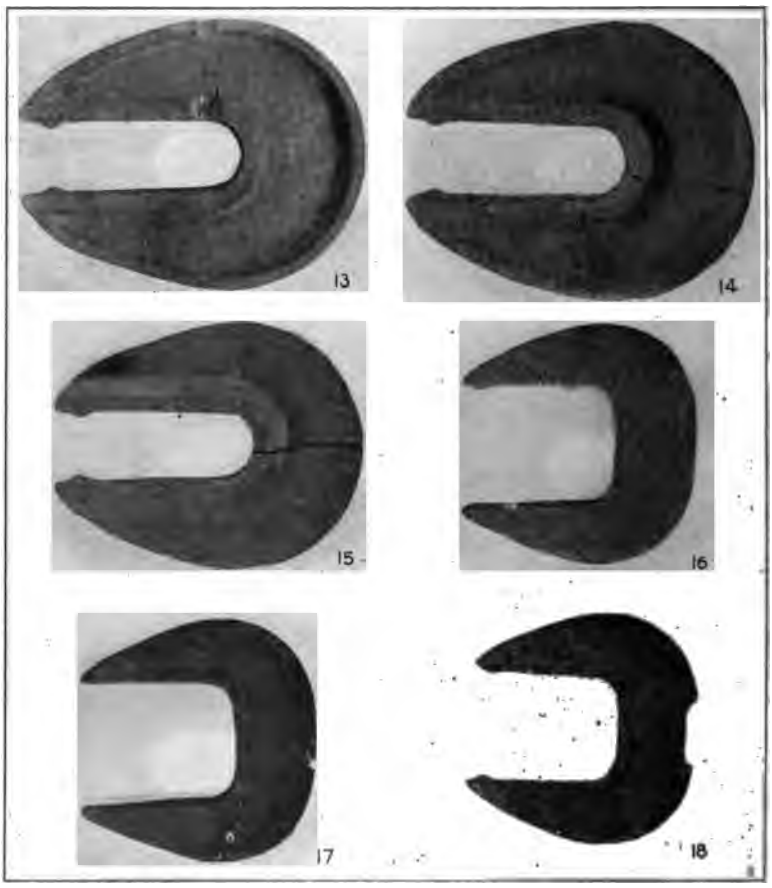


PLATE III CURVED CAST-IRON SPECIMENS BROKEN BY TESTS

strength varied from 36,400 to 46,400 lb. The variations in the values of K seem to indicate that no definite relation exists between the tensile and flexural strength of small test bars.

11 The determination of the correct value for the radius of curvature of the gravity axis is extremely important and considerable care

was exercised in attempting to get accurate measurements of these values by plotting the curve of the gravity axis and finding its radius of curvature at the section considered in each case. It is possible for the personal equation to cause sufficient variations in these values to affect appreciably the final results. The chances for errors in plotting the transformed curves and measuring their areas is also worthy of the designer's consideration in choosing a formula.

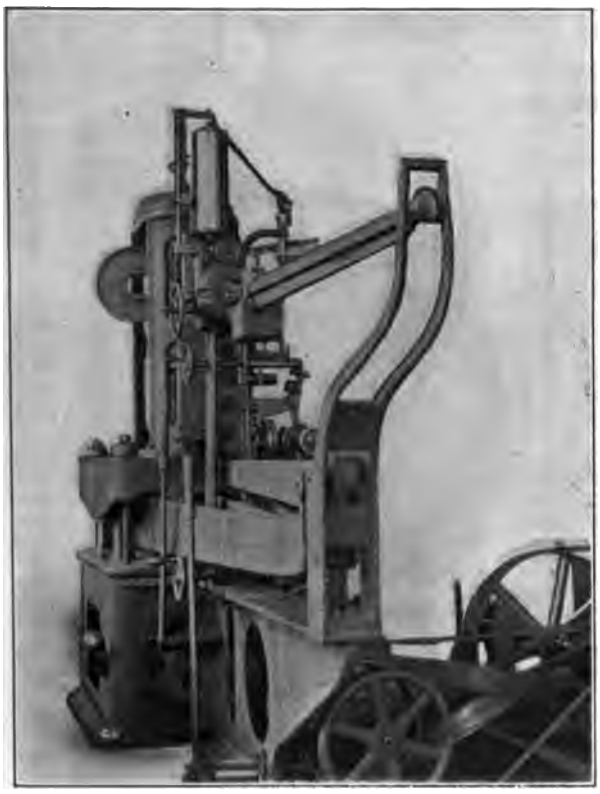


FIG. 5 100,000-LB. RIÉHLE TESTING MACHINE

12 The average dimensions of castings No. 1, 2, and 3, Plate I, cast from the same pattern, are given in Fig. 1. Each casting was carefully measured and the values used in the respective calculations. The average tensile strength of the three test bars is 18,907 lb. per sq. in. The maximum stress in the castings at failure as given by the beam formula is 14.2 per cent less than the tensile strength of the

test bar, whereas the stress according to the Résal and Pearson-Andrews formulae is 43.4 per cent and 75.4 per cent in excess of the strength of the test bar.

13 From Keep's experiments it is known that the unit strength of cast-iron bars of the same composition decreases as the area increases; hence, it is reasonable to suppose that the unit stress given by the beam formula is very close to the actual ultimate strength of the material.

FIG. 6 METHOD EMPLOYED IN APPLYING LOAD

The absurd results given by the Résal and Pearson-Andrews formula show that they are not applicable to the case in question.

14 Castings No. 4, 5, 7, 9 and 12, Plates I and II, were cast from the same pattern and the average dimensions are given in Fig. 2. None of the above-mentioned formulae apply to these castings owing to the peculiar manner in which they failed. The results, however,

ıave an extremely important bearing on the design of punch frames. Γhese specimens were supposed to fail under a load of about 15,000 b. When the load on No. 4 reached 9300 lb. a fracture occurred ɔehind the inner flange, as shown in the photographs of castings No. 7 and 12. Continued application of the load produced the fractures shown on No. 4, 5 and 9. The stress producing failure was evidently a normal stress as there is no shear on this section.

TABLE 1 RESULTS OF TESTS

	Tension Specimens			Transverse Specimens Length 12 in.				Curved Specimens			
									Unit stress at *ab*		
Test No.	Breaking Load	Area Sq. In.	Stress Pounds Per Sq. In.	Breaking Load	Area (Breadth × Depth)	$S = \frac{MC}{I}$	$K = S_t \frac{bd^2}{M}$	Breaking Load	Beam Formula	Réal's Formula	Pearson-Andrews Formula
1	18000	0.785	19100	2380	.75 × 1.25	36560	3.14	11200	16240	27025	33013
2	14630	0.785	18630	2380	.75 × 1.25	44200	2.52	11125	16120	26844	32796
3	13460	0.709	19000	1630	1.25 × .75	46080	2.65	11390	16540	27484	33577
4	17060	0.785	21630	2280	1 × 1.05	37200	3.48	9300	11330	19583	38223
5	17000	0.785	21630	2000	1 × .95	40000	3.25	8500	10500	17909	34935
6	18500	0.833	18600	2160	1 × 1	39000	2.86	12600	22520	25870	29460
7	16200	0.866	18750	2380	1 × 1	43000	2.62	12000	9790	12584	27048
8	16070	0.734	21700	2310	1 × .95	46350	2.82	15300	12600	18420	
9	18000	0.785	22930	2300	1 × 1	39600	2.97	8300	10130	19164	36530
10	18000	0.785	20370	2300	.95 × 1	43700	2.70	8400	10520	—	—
11	17800	0.754	23600	2060	1.02 × 1	36400	3.94	5200	18420	21040	
12	18000	0.785	23000	2070	1 × .98	38000	3.56	8400	10235	17500	34524
13	18000	0.754	24400	2440	1 × .98	45000	3.20	5800	—	—	—
14	16200	0.739	21800	2300	1.02 × 1	40600	3.22	12700	23920	26435	28700
15	16100	0.754	21400	2240	1 × 1	40400	3.18	12500	23400	26025	28250
16	16730	0.785	21270	2460	.75 × 1.25	37800	3.41	11255	16320	27160	33300
17	17340	0.785	22080	2741	.75 × 1.25	42200	3.17	11980	17270	28987	35400
18	17900	0.785	22800	2680	.75 × 1.25	41300	3.35	10600	21476		

15 The conditions of stress that would produce such a failure may be given as follows:

a The inner flange being heavier than the web would tend to produce separation behind the flange due to unequal contraction when cooling. This initial stress due to cooling, plus the stress due to lateral contraction caused by the tensile stress due to bending, is a stress normal to the plane of

fracture. This method gives about 1500 lb. for the stress due to the load and about 18,000 lb. for the initial stress due to cooling, which is considered absurd. Hence this method does not offer a satisfactory explanation.

b In Fig. 7, the load W produces a bending moment at the section AD equal to WN. This moment is resisted by the moment $\frac{SI}{c}$ where S is the stress at A, I the moment of inertia of the section between A and D, and c the distance between the center of gravity of this section and the point A. The fracture of casting No. 5 suggested this method as a possible cause of failure. At a load of 8500 lb. a fracture occurred behind the inner flange and the load dropped almost to zero. Upon further application of the load the crack gradually approached the outer flange, then the inner flange fractured and finally the outer flange separated. According to this method of analysis the average unit stress at A in the five castings was about 22,700 lb. when the fracture occurred, which is excessive for tensile strength. This does not take into consideration a possible shifting of the neutral axis, however, which would tend to decrease the value of the result. There are also reasons for using a larger value for N. By changing the values of N and c, it is possible to change the value for the stress, hence this method could not be relied upon without making many tests on different-sized specimens with different thicknesses of flange.

c Considering the flanges as separate members having pin connections at points A, E, F and G in Fig. 8, the load W would tend to increase the distance between the points A and G. If A and G be connected by means of a link, the stress in it may be found as follows: Draw the lines EG, FG. EA, and FA and let them represent links with pin connections. Then produce GA until it cuts the line of application of the load at K. The triangle AKE may be taken as the force diagram where $KE = \frac{W}{2}$ and KA is equal to half the stress in the link AG. In the specimen, this stress is taken by the web, the area of which is the outside

diameter, *pp*, of the inner flange multiplied by the thickness of the web. According to this method the unit stress is about 18,000 lb., which seems to express the stress relation very satisfactorily for this particular case, but it is not probable that such results would be derived from castings having a thicker flange.

16 Casting No. 7, Plate II, was first subjected to a compressive load acting on the horizontal side of the notches cut in the outer flange. This caused failure near the line of application of the load, as shown in the photograph. It was then subjected to a tensile load acting at a distance of $5\frac{3}{16}$ in. from the inside of the spine, and failed similar to No. 5.

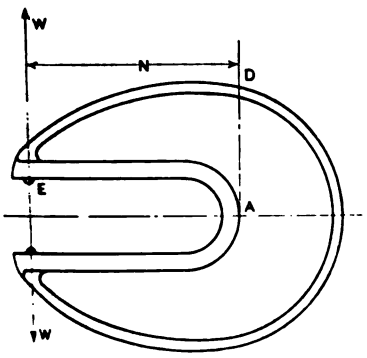


FIG. 7 DIAGRAM SHOWING CONDITION WITH BENDING MOMENT AT SECTION *AD*

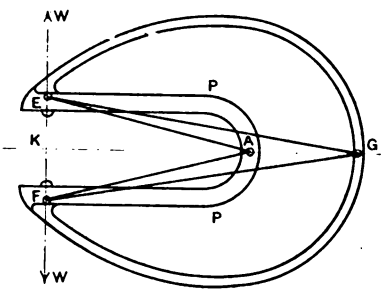


FIG. 8 DIAGRAM SHOWING CONDITION PRODUCING TENSILE STRESS IN SECTION *AG*

17 Casting No. 9 had $\frac{3}{16}$ in. of the outer flange removed on both sides. This, however, did not seem to affect its strength, failure occurring behind the flange.

18 Casting No. 12 had the outer flange removed on both sides and the inner flange reduced to a width of 1 in. at a distance of $6\frac{1}{2}$ in. from the load line; but this did not seem to affect its strength, as failure occurred behind the flange similar to No. 5. The unit stress at the milled section according to the formula $S = \frac{Mc}{I}$ was 34,805 lb.

19 Casting No. 10 had the inner flange reduced to a width of $2\frac{1}{4}$ in. and failed horizontally as shown. Failure in this manner was probably due to a flaw in the inner flange that extended into the web.

20 Casting No. 11 had about 2 in. of the outer flange removed on both sides and the width of the inner flange reduced to 2 in.

21 Casting No. 13, Plate III, had both flanges removed at a distance of 6.8 in. from the line of application of the load. The stress at this point according to the formula $S = \frac{Mc}{I}$ is 31,160 lb. per sq. in.

22 Casting No. 6 is the same as shown in Fig. 2 with the exception of having the thickness of the web increased to 0.93 in. The fracture occurred at an angle of about 30 deg. with the horizontal. There seemed to be a tendency for the fracture to follow the inner flange.

23 Casting No. 8 was subjected to a compressive load and failed at a section 7 in. from the line of application of the load, the stress being 35,370 lb. according to the formula for beams.

24 Casting No. 14 had the thickness of the web increased to 0.93 in. and provided with large triangular fillets behind the inner flange. By comparing the results of this test with those from No. 6, it seems that enlarging the fillet does not appreciably affect the strength of the casting.

25 Casting No. 15 is the same as No. 14 with the outer flange removed. The results seem to show that the outer flange on No. 14 adds but little to its strength.

26 Casting No. 16 failed in a curved portion. The angle between the plane of fracture and line of application of the load is about 79 deg. The stress in this section by Formula 7 (see Par. 64) was 16,300.

27 Casting No. 17 failed in a curved portion, the angle being about 48 deg. The stress in the fractured section by Formula 7 (see Par. 64) was 17,300.

28 Casting No. 18 is the same as No. 16 and No. 17 with the depth of spline reduced to 3.4 in. The stress at fracture was 21,476.

THE AUTOGRAPHIC RECORDER

29 The autographic recorder gave an apparently straight line for the deflection-load diagram for each specimen, but the scale of the curve is so small that a slight curvature due to the elastic law would not be perceptible. It is interesting to know, however, that the curve is so nearly a straight line and does not show any change in the elastic law which might be taken as the elastic limit of the specimen.

30 The load-deflection curve shows the total deflection produced by any given load on the specimen, and a sudden change in its direction would indicate that the stress in some section had reached the

l point. Any method of analysis involving the use of these curves plicable only to the section which yields first. In the case of steel imens it is difficult to determine this section, and in the analysis resses in cast-iron specimens the diagram finds no application.

CONCLUSIONS

Although these experiments are not sufficiently exhaustive to er any rigid conclusions, they seem to indicate that the following ments are approximately true:

a There is no rational method for predicting the strength of curved cast-iron beams suitable for punch and riveter frames.

b Of the three formulae suggested for the design of punch frames, the well known beam formula

$$S = \frac{Mc}{I} + \frac{W}{A}$$

is the most accurate statement of the law of stress relations existing in such specimens.

c The stress behind the inner flange at the curved portion is an important consideration that should be recognized by the designer.

d There seems to be no definite relation existing between the strength of a curved cast-iron beam and the transverse strength of a test bar cast with it.

e The Résal and Pearson-Andrews formulae are unwieldy and awkward in their application and offer many chances for error.

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cknowledgment is due to Prof. S. E. Slocum for criticisms during the paration of this article and to Prof. John T. Faig whose assistance made sible the securing of the materials necessary for conducting the tests.

APPENDIX

ELASTIC LAW

32 Within the elastic limit, homogeneous materials such as steel and wrought iron conform with Hooke's law, which states that the stress varies directly as the strain; hence the stress-strain diagram is a straight line. In common practice the elastic limit for cast iron is assumed to be about 6000 lb. per sq. in. and Hooke's law is supposed to be practically true for stresses not exceeding this value; but, as a matter of fact, cast iron has no clearly defined elastic limit like steel, and no portion of the stress-strain diagram is a straight line. The elastic law in this case may be expressed by the exponential equation

$$\Delta = K S^m$$

where Δ denotes the unit deformation, S the unit stress, and K and m are constants. From the experiments of Bach these constants have been determined for cast iron, and the elastic laws found to be as follows:

$$\text{For tension, } \Delta = 0.00000004126\, S^{1.0663}$$

$$\text{For compression, } \Delta = 0.00000005415\, S^{1.0395}$$

33 These experimental curves may be replaced by parabolas without introducing any serious error. From experiments by Hodgkinson, the equations of the parabolas which fit these stress-strain diagrams most closely were found to take the form

$$S = 1{,}400{,}000\,\Delta\,(1 - 209\,\Delta), \text{ for tension}$$

$$S = 1{,}300{,}000\,\Delta\,(1 - 40\,\Delta), \text{ for compression}$$

34 By assuming that the equation of the elastic law is a parabola, the stress in a beam at a distance y from the neutral axis was expressed by St. Venant in the equations

$$S = T\left[1 - \left(1 - \frac{y}{c}\right)^m\right], \text{ for tension}$$

$$S' = C\left[1 - \left(1 - \frac{y}{c'}\right)^m\right], \text{ for compression}$$

where T and C denote the ultimate tensile and compressive strengths, c and c' the distance from the neutral axis to the extreme fiber in tension and compression respectively, and m is a constant so chosen as to make the parabola fit the stress-strain diagram for the given material. For the value $m = 1$, these equations reduce to the form

$$S = T\,\frac{y}{c}$$

which is Hooke's law.

POSITION OF THE NEUTRAL AXIS AND THE MOMENT OF RESISTANCE

35 The equation

$$M = \frac{SI}{c}$$

is commonly known as the fundamental formula for beams. This formula is due to Navier and is based on the following assumptions: first, the strain is directly proportional to the distance from the neutral axis; second, the neutral axis coincides with the gravity axis; third, the stress is directly proportional to the strain on both the tension and compression sides. Some authorities favor the validity of the first assumption, but they all in general agree that the second and third are not true for cast iron.

36 The fact that the flexural strength given by the above formula does not coincide with the tensile strength has reflected discredit upon it. The flexural strength is from 1.5 to 2 times the tensile strength for ordinary test bars. The cause of this discrepancy is frequently explained by saying that the formula is based on Hooke's law, and is not expected to hold true above the elastic limit, hence it does not give the actual tensile strength at rupture. This statement, however, is not necessarily true, because the formula will represent the stress relations in a rectangular beam under all conditions of load provided the coefficients of elasticity for tension and compression are equal.

37 The discrepancy is due to the shifting of the neutral axis which is caused by the difference in the elastic laws for tension and compression. A method for determining the position of the neutral axis is given by St. Venant in his notes on Navier's Resistance of Solid Bodies. Assuming that the strain varies directly as the distance from the neutral axis, the stress will vary as in the ordinary stress-strain diagram. Now if the beam fails in tension, the stress at rupture on the extreme fiber on the tension side is equal to the ultimate strength of the material.

38 Let $BE = S_t$ represent the ultimate tensile strength of the material, and let OE and ODF represent the stress-strain diagrams for tension and compression respectively as shown in Fig. 9. Then OB is the distance of the neutral axis from the tension side of the beam drawn to the same scale as yet undetermined, and the area OEB represents the total tensile stress in the beam at this section. But since the total tensile and compressive stresses must be equal, the compressive side of the beam is found by drawing a line AD such that the area OAD is equal to the area OEB. OA will then represent the distance of the compressive side of the beam from the neutral axis to the same scale as that to which OB is drawn. The scale may be easily determined by comparing AB with the actual depth of the beam.

39 The stress-strain diagram for the compression side is more nearly a straight line than that of the tension side. By assuming that the compression side obeys Hooke's law, the formula for the moment of resistance is thereby simplified and becomes for a rectangular section of breadth b and depth d

$$M = S\frac{bd^2}{6}\left[\frac{m\left(\frac{3(m+3)}{m+2} + 4\sqrt{\frac{2}{m+1}}\right)}{m+3+2\sqrt{2(m+1)}}\right]$$

The value of m in this equation is to be so chosen as to make the expression for the elastic law conform as closely as possible with the actual stress-strain diagram. This equation for any given material reduces to the form

$$S = \frac{MK}{bd^2}$$

40 Hodgkinson's[1] experiments led him to conclude that the neutral axis did not coincide with the gravity axis just at the point of failure of a cast-iron beam, and that it moved toward the compression side, dividing the depth into a ratio of 1:5 or 1:6, which is the ratio of the ultimate strengths of the material in tension and compression.

41 W. H. Barlow[2] experimented with beams 7 ft. long, 6 in. deep and 2 in. wide, and found that loads less than three-fourths of the breaking load did not change the neutral axis materially, but just before rupture the shifting became greatly increased. These experiments accounted for only a small percentage of the discrepancy assumed by Hodgkinson.

42 Another explanation is that the outer fibers are subjected to an initial compressive stress due to their being cooled before the inner portion of the beam, and this initial stress must be overcome before the tensile stress begins.

43 Lewiston[3] proposed the theory that the compression side of a cast-iron beam is stressed to its ultimate strength at the point of failure. That is to say, a beam is stressed to its ultimate strength on both the compressive and tensile sides just before failure occurs. According to his theory, the distance from the neutral axis to the fiber that fails first is

$$X = \frac{I}{C + T}\, d$$

where C and T are the ultimate strengths in compression and tension and d the depth of the beam. As a result of this theory the moment of resistance of a rectangular cast-iron beam is

$$M = \frac{5}{18}\, Sbd^2$$

when the ratio of the ultimate strengths, $\frac{c}{T}$, is equal to 5. This equation may also be written

$$S = \frac{MK}{bd^2}$$

where S denotes the ultimate strength of the material in tension.

44 Emery[4] claims that neither Hooke's law nor Bernoulli's assumption are true for cast iron, that the medial portion between the neutral axis and the extreme fibers is stressed more than assumed by Bernoulli's assumption, which would necessarily relieve the outer fiber of a certain amount of stress. In devel-

[1] Hodgkinson: Experimental Researches on Cast Iron.
[2] Phil. Mag. 1855.
[3] Trans. Am. Soc. C. E., Vol. 35.
[4] Trans. A. S. M. E. Vol. 8.

oping a formula for the resistance of a rectangular cast-iron beam he assumes the elastic law

$$\Delta = KS^m$$

for the tension side and Hooke's law for the compressive side, which gives

$$M = Sbd^2 \frac{(n + \frac{2}{3}\frac{m}{\sqrt{2\,mt}})}{(1 + \sqrt{2\,mt})^2}$$

where S is the tensile strength of the material, n and m are constants from integration and t the ratio into which the neutral axis divides the depth of the beam. This equation may also be expressed

$$S = \frac{MK}{bd^2}$$

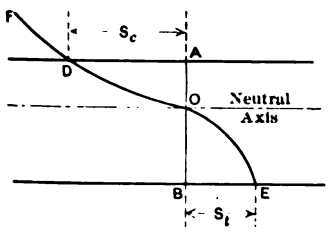


FIG. 9 STRESS-STRAIN DIAGRAM FOR TENSION AND COMPRESSION

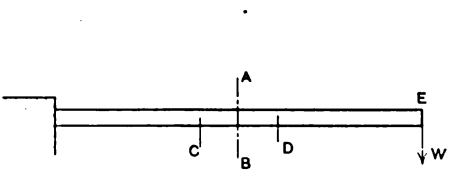


FIG. 10 CANTILEVER BEAM SUBJECTED TO A BENDING MOMENT

The values of K given by Mr. Emery range from 2.8 to 4.

45 Clark's formula

$$S = \frac{WL}{1.55\,bd^2}$$

gives a value of $K = 3.46$.

46 Keep[1] published the results of a great many tests of different-sized specimens made of different grades of cast-iron and concludes that the silicon content and the rate of cooling greatly affects the strength of cast-iron. He also points out the fact that there is definite relation existing between the shrinkage and the percentage of silicon, and by measuring the shrinkage of a bar, the silicon content may be found from his shrinkage chart. This same chart is also provided with curves from which the strength of any bar between ½ in. and 4 in. sq. may be found when the strength of any other bar within these limits is known. In the discussion of Mr. Keep's paper, Professor Benjamin proposed the formula

$$W = H\frac{b^{0.83}d^{1.89}}{L^{1.058}}$$

[1]Trans. Am. Soc. M. E., vol. 17.

where W is the breaking load and H a constant determined by breaking a b
1 in. square and 12 in. long.

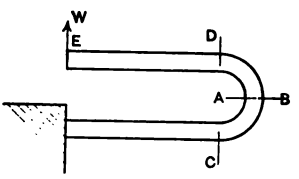


FIG. 11 BENT CANTILEVER BEAM SUBJECTED TO A BENDING MOMENT

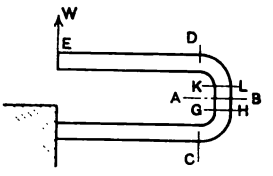


FIG. 12 BENT CANTILEVER BE WITH STRAIGHT SPINE SUBJECTED TO A BENDING MOMENT

47 Although based upon different theories and experiments, most of t
above formulae for straight cast-iron beams of rectangular cross-section redu
to the form

$$S = \frac{MK}{bd^2}$$

For rectangular sections the value of K has been found to vary between 2.8 an
4, depending upon the elastic laws of the material when subjected to tensile an

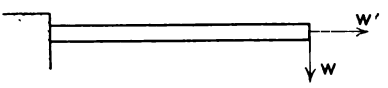


FIG. 13 STRAIGHT BEAM SUBJECTED TO COMBINED BENDING AND LONGITUDINAL TENSION

compressive stresses; and these laws vary with the sectional area, chemical co
position, temperature of the metal when poured and the rate of cooling.

EFFECT OF CURVATURE AND FORMULAE FOR CURVED BEAMS

48 In Fig. 10 the simple cantilever beam is subjected to a bending mom
due to the load W supported at the end. The bending moment at the sect
AB is resisted by the tensile and compressive stresses in the upper and lo
fibers of the beam.

49 Consider the beam when bent into the forms shown in Fig. 11 and Fig.
The condition of stress in the portion ED is not affected by the change in sha
whereas the section AB resists not only the bending moment due to the lo
but an additional force due to the direct pull of W.

50 The stresses in any section of a straight beam subjected to a bend
load W, and a tensile load W' as shown in Fig.13, may be accurately re
sented by the well known formulae

$$S_t = \frac{Mc}{I} + \frac{W'}{A}$$

$$S_c = \frac{Mc}{I} - \frac{W'}{A}$$

51 These formulae are supposed to be true for straight portions of beams only; but due to their simple form, they are often applied to curved sections such as AB in Fig. 11; in which case $W' = W$ and $M = WL$, where L is the distance from line of application of the load to the gravity axis. When used in this way these formulae assume that the neutral axis coincides with the gravity axis of the section and its position is not affected by the curvature of the beam. These formulae may also be written in the form

$$S_t = \frac{W}{A}\left(\frac{Lc}{R^2} + 1\right) \quad \ldots\ldots [1]$$

$$S_c = \frac{W}{A}\left(\frac{Lc}{R^2} - 1\right)$$

where R is the radius of gyration and equal to

$$\sqrt{\frac{I}{A}}$$

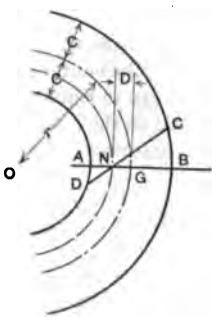


FIG. 14 ENLARGEMENT OF CURVED PORTION FIG. 11

52 Fig. 14 shows an enlargement of the curved portion of the beam represented in Fig. 11. Assuming that a plane passed through the section AB before the load is applied remains a plane under the conditions of stress, that the stress is directly proportional to the distance from the neutral axis, and the radius of curvature of the gravity axis does not change; it will take less stress to deform the fibers on the convex side the same amount as on the concave side, because the convex side is longer. When the stresses at A and B are equal, the deformations may be represented by BC and AD respectively. The neutral axis does not coincide with the gravity axis at G, but passes through the point N which is nearer the convex or tension side, and at a distance D from G. The distance D, through which the neutral axis shifts, is independent of the stress when expressed by the equation[1]

$$D = -\frac{\int \frac{y\,dA}{y + r}}{\int \frac{dA}{y + r}} \quad \ldots\ldots [2]$$

[1] This method of analysis is due to Résal and is given in Strength of Materials by Slocum and Hancock.

where y denotes the distance from the gravity axis to any fiber having an area equal to dA, and r the radius of curvature OG of the gravity axis.

53 The stress on any fiber at a distance y from the gravity axis is expressed by the equation

$$S = \frac{M}{(y+r)} \frac{(y+D)}{\int \frac{(y+D)^2}{y+r} dA} \quad \text{.....[3]}$$

where the bending moment, $M = W(L-D)$.

54 The application of the above formula may be greatly simplified by a geometrical transformation of the section as shown in Fig. 15. Let *KLMN* represent a section cut by the plane *AB* in Fig. 11, *OS* the axis of symmetry passing through the center of curvature *O* and *GP* the gravity axis of the section perpendicular to *OS*. By drawing radial lines from *O* through each point in the boundary, such as *T*, cutting the gravity axis at some point *R*, the lines drawn through *T* and *R*, perpendicular to *OS* and *GP* respectively, will intersect in the point *E*. The locus of the point *E* is the boundary of the transformed curve *klmn*.

55 It has been proven by Résal that the distance between the center of gravity *G* of the original section and the center of gravity *G'* of the transformed section is equal to the value of *D* given in Equation 2, and the moment of inertia of the transformed section is equal to the integral in Equation 3. By denoting the moment of inertia of the transformed section by *I'*, the above equation reduces to

$$S = \frac{Mr}{I'} \cdot \frac{y+D}{y+r} \quad \text{.....[4]}$$

56 Another method of analysis is that due to Pearson and Andrews which takes into account the change in the radius of curvature and decrease in cross sectional area due to lateral deformation. The tensile stress on the concave side is expressed by the formula

$$S = \frac{W}{A}\left[\frac{L}{r r_2}\left(\frac{1}{\left(1-\frac{c}{r}\right)^{n+1}} - r_1\right)+1\right] \quad \text{.....[5]}$$

where

W = load in pounds;
A = area of cross-section in square inches;
L = distance from line of application of load to the gravity axis of the section;
r = radius of curvature of gravity axis in inches;
c = distance from gravity axis to extreme fiber on tension side;
n = Poisson's ratio of lateral contraction.

The value of r_1 is determined graphically as follows: Let *KLMN* in Fig. 1 represent the cross-sectional area cut by the plane *AB* in Fig. 11; r the radius of curvature, *GP* the gravity axis and y the distance from any point *C* on the boundary to the gravity axis. For each value of y, or position of *D* lay o

$$CE = \frac{CD}{\left(1+\frac{y}{r}\right)^{n+1}}$$

forming the boundary *klmn*. The area of *klmn* divided by the area of the section *KLMN* is equal to the value of γ_1.

57 The value of γ_2 is equal to

$$\frac{\text{area of } klmn - \text{area } k'l'm'n'}{\text{area of } KLMN}$$

where the boundary of the area $k'l'm'n'$ is formed by making

$$CJ = \frac{CD}{\left(1 + \frac{y}{r}\right)^n}$$

for each value of y.

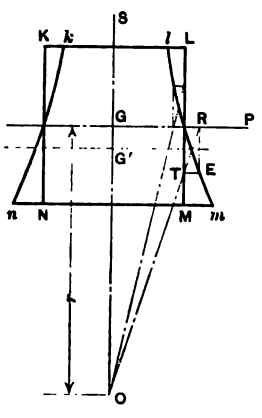


FIG. 15 GRAPHICAL DETERMINATION OF THE INTEGRAL IN EQUATION [3]

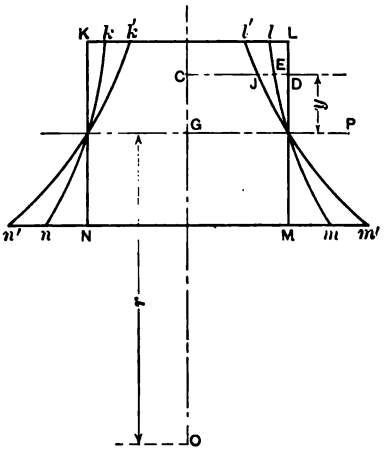


FIG. 16 GRAPHICAL DETERMINATION OF y_1 AND y_2 FOR EQUATION [5]

58 The stress in any section of the straight portion of the beam shown in Fig. 11 may be found from the formula

$$S = \frac{Mc}{I}$$

and the stress in a section perpendicular to the line of application of the load, such as *AB*, may be found from Formula 4, provided the beam is of homogeneous material and obeys Hooke's law, but none of the above formulae can be accurately applied to the section between *A* and *C*.

59 It is not necessary, however, to investigate more than one section of the curved portion provided the throat depth is small, as in the case of hooks; but in designing large punch frames it is desirable to determine at least two sections within the curved portion.

60 By comparing the properties of cast iron with the assumptions upon which the Formulae 1, 3, and 4 are based, it is easily seen that they do not apply to cast iron with any degree of accuracy. Hodgkinson's experiments

seem to show that due to the properties of the material, the neutral axis c cast-iron beam shifts toward the compression side a distance

$$D' = \frac{d}{3}.$$

Résal's formula as given in Equation 2 when applied to a rectangular sect shows that

$$D = r - \frac{d}{\log_e \frac{2r + d}{2r - d}}$$

61 If the radius of curvature be such as to make $D' = D$, it seems t Formula 1 would apply. By equating the values of D and D' and solving, 0.0505 d, which is a value that could not be used in practice. Hence, thei apparently no rational formula that represents the relation between the br ing load and the unit strength of curved portions of cast-iron beams sin in form to that shown in Fig. 11.

62 Press and punch frames requiring a wide gap are usually shaped simil to the beam shown in Fig. 12, in which case a portion of the spine is strai The sections KL and GH may be considered as belonging to either the stra or curved portions. If considered as belonging to the curved portion Forn 4 should apply; but if taken as belonging to the straight portion it is subje to the same conditions of stress as the section AB, and Formula 1 shoul applicable. These formulae, however, give different results which seen indicate that the section AB should be less than the sections KL and G the curved portions, hence the condition of stress at KL and GH is somev similar to that due to sudden change in cross section, or which exists in the tion connecting a spherical end to a thick cylinder.

63 A formula for determining the ultimate strength of castings ha straight spines should recognize the change of the neutral axis due to the el properties of cast iron. Such a formula based on the knowledge of stra beams of rectangular section takes the form

$$S = \frac{MK}{bd^2} + \frac{W}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots$$

where K is a constant to be determined experimentally.

64 The stress at sections between A and D in Fig. 11 and in sections al KL in Fig. 12 are usually determined by the formula

$$S = \frac{Mc}{1} + \frac{W \sin \theta}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots$$

where M is the product of the load into the distance between the line of a cation of the load and the gravity axis of the section considered; and θ angle between the line of application of the load and the section produced t they intersect. For rectangular sections this formula may also be wri

$$S = \frac{MK}{bd^2} + \frac{W \sin \theta}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots$$

DISCUSSION[1]

WALTER RAUTENSTRAUCH. I was much surprised to find that Professor Jenkins' experiments with cast-iron frames of the C form had led him to the conclusion that the Andrews and Pearson formula gave results which were absurd when compared with those obtained by experiment. That the analysis should be so very incorrect when applied to cast iron was quite contrary to the opinion I had held after my experiments with hooks of wrought iron and cast steel, the results of which are reported in the American Machinist, October 7, 1909.

The table of breaking loads and maximum stress at breaking load, a quantity I have never been able to compute by any standard formula, is interesting but not at all adapted to throw any light on the subject of the relation between load and maximum intensity of

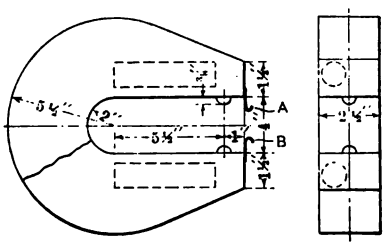


FIG. 17 DIMENSIONS OF TEST SPECIMENS

stress in cast-iron frames of this sort. In order that I might learn the true state of affairs at first hand, I had a few castings prepared similar to the one shown in Fig. 1 and tested them. The results of these tests follow.

Four castings with dimensions as shown in Fig. 17 were prepared, two by the Isaac G. Johnson Company and two by another firm. The latter two were found to be very defective, being full of blow holes and imperfections which made the results of tests on them of no value. The C castings were tested in a Riéhle 100,000-lb. testing machine, and the separation of the points A and B were read by a micrometer caliper to ten-thousandths of an inch. Loads and read-

[1]The discussion is here published in abstract only. The complete discussion appeared in The Journal for September 1910.

ings were taken, as shown in Table 2. Casting No. 1 br shown in Fig. 17. The relation between load and opening is in Fig. 18.

TABLE 2 TESTS ON CASTING NO. 2

Load	Caliper Reading	Total Opening	Load	Caliper Reading	Tota
0	.....	.....	10500	0.3420	
500	0.2621	.....	11000	0.3468	
1000	0.2642	0.0021	11500	0.3515	
1500	0.2675	0.0054	12000	0.3567	
2000	0.2712	0.0091	12500	0.3617	
2500	0.2745	0.0124	13000	0.3702	
3000	0.2783	0.0162	13500	0.3738	
3500	0.2824	0.0203	14000	0.3772	
4010	0.2862	0.0241	14500	0.3822	
4500	0.2891	0.0270	15000	0.3878	
5000	0.2944	0.0323	15500	0.3942	
5500	0.2988	0.0367	16000	0.4000	
6000	0.3025	0.0404	16500	0.4050	
6500	0.3068	0.0447	17000	0.4102	
7000	0.3110	0.0489	17500	0.4172	
7500	0.3153	0.0532	18000	0.4228	
8000	0.3200	0.0579	18500	0.4296	
8500	0.3242	0.0621	19000	0.4354	
9010	0.3282	0.0661	19500	0.4432	
9500	0.3329	0.0708	20000	0.4493	
10000	0.3380	0.0759	20500	0.4569	
			21000	Broke	

TABLE 3 TESTS ON CASTING NO. 2

Load	Caliper Reading	Total Opening	Load	Caliper Reading	Tota
0	.....	.....	11070	0.3795	
500	0.2951	.....	12000	0.3885	
1080	0.2981	0.0030	13020	0.3992	
2040	0.3050	0.0099	14010	0.4079	
2930	0.3123	0.0172	14970	0.4207	
4030	0.3202	0.0251	15770	0.4300	
5050	0.3279	0.0328	16810	0.4417	
7040	0.3450	0.0499	18010	0.4548	
8030	0.3533	0.0582	18980	0.4677	
9000	0.3611	0.0660	20000	Broke	
10030	0.3709	0.0758			

In tests on casting No. 2 (Table 3) the piece broke in th manner as casting No. 1 and as shown in Fig. 17. Fig. 1! graphically the rate of opening with increase of load.

Tension-test specimens and compression-test specimens of standard form were cut from each casting, as shown by dotted lines in Fig. 17, and tested in an Emery hydraulic testing machine of 200,000-lb. capacity (Tables 5 and 6). The results are plotted in Fig. 20 and Fig. 21. The compression specimen from casting No. 1 was ruined and could not be used. The results of the tests on the specimen from casting No. 2 are shown in Table 4 and Fig. 21.

From the dimensions of the principal cross section of castings Nos. 1 and 2, as shown in Fig. 17, the functions γ_1 and γ_2 of the Andrews and Pearson formula were computed graphically and checked by analytical methods, giving $\gamma_1 = 1.126$, $\gamma_2 = 0.119$. The radius

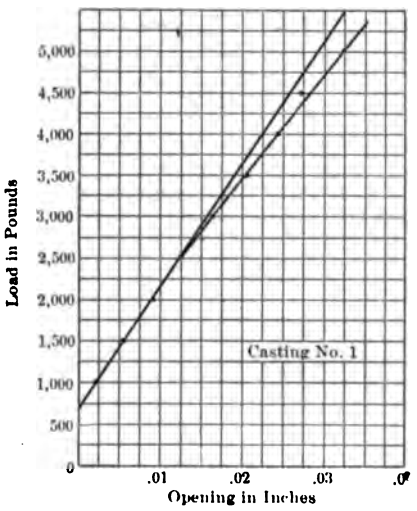


FIG. 18 RATE OF OPENING WITH INCREASE OF LOAD

of curvature of the belly of the casting was found to be $r = 3.75$ in. The distance from the point of application of the load to the center of gravity of the principal cross section was found to be $L = 9.3$ in. The distance from the center of gravity to the point most strained in tension was found to be $c = 1.8$ in. The area of the section was 9 sq. in. The moment of inertia of the section about the gravity axis was 9.72 biquad. in. The modulus of elasticity in compression was about 14,600,000 and the modulus of elasticity computed from the readings of the extensometer about 9,000,000 in the first case and about 6,000,000 in the second case.

TABLE 4 COMPRESSION TEST ON CASTING NO. 2

DIAMETER OF SPECIMEN = 1 IN.

Actual Load	Load per sq. in.	Total Compres.	Actual Load	Load per sq. in.	Total
0	....	.....	8000	10200	0
500	637	0.00005	9000	11460	0
1000	1273	0.00010	10000	12720	0
1500	1910	0.00015	15000	19100	0
2000	2550	0.00015	20000	25440	0
2500	3180	0.00020	25000	31800	0
3000	3820	0.00020	30000	38200	0
3500	4460	0.00035	35000	44600	0
4000	5100	0.00035	40000	51000	0
5000	6360	0.00055	45000	57400	0
6000	7650	0.00070	50000	63600	0
7000	8900	0.00090	89800	114600	1

TABLE 5 TENSION TEST ON CASTING NO. 2

DIAMETER OF SPECIMEN = 0.503 IN.

Actual Load	Load per sq. in.	Total Extension	Actual Load	Load per sq. in.	Total
0	0	0.00000	3000	15000	0
500	2500	0.00045	3500	17500	0
1000	5000	0.00100	4000	20000	0
1500	7500	0.00155	4500	22500	0
2000	10000	0.00210	5000	25000	0
2500	12500	0.00270			1

TABLE 6 TENSION TEST ON CASTING NO. 1

DIAMETER OF SPECIMEN = 0.506 IN.

Actual Load	Load per sq. in.	Total Extension	Actual Load	Load per sq. in.	Total
0	....	.....	2500	12500	0.
500	2500	0.00030	3000	15000	0.
1500	5000	0.00060	3500	17500	0.
1500	7500	0.00095	4000	20000	
2000	10000	0.00165			

Grips slipped at 4000lb. and the experiment was discontinued.

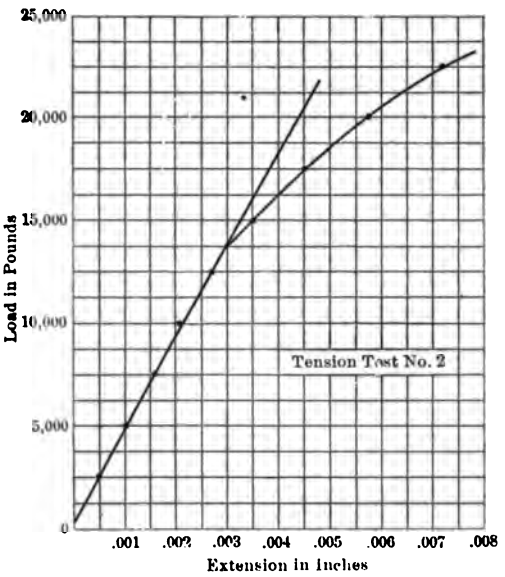


FIG. 20 STRESS-STRAIN DIAGRAM

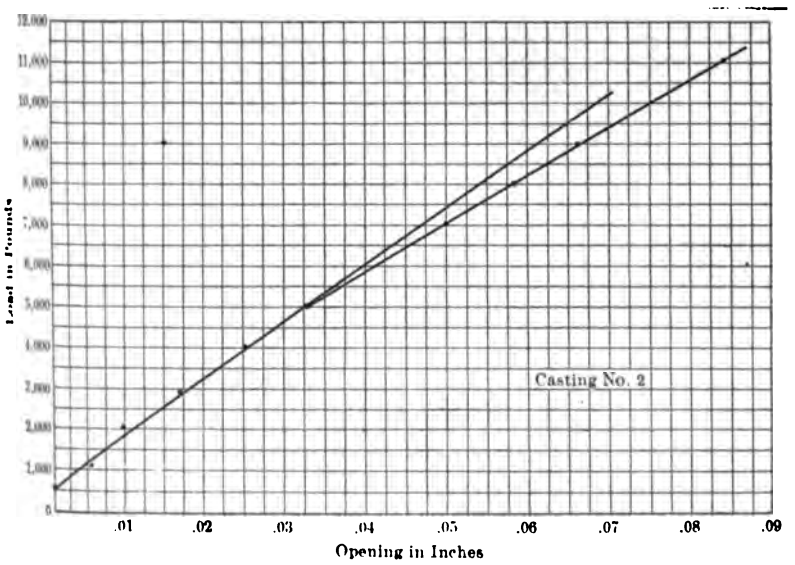
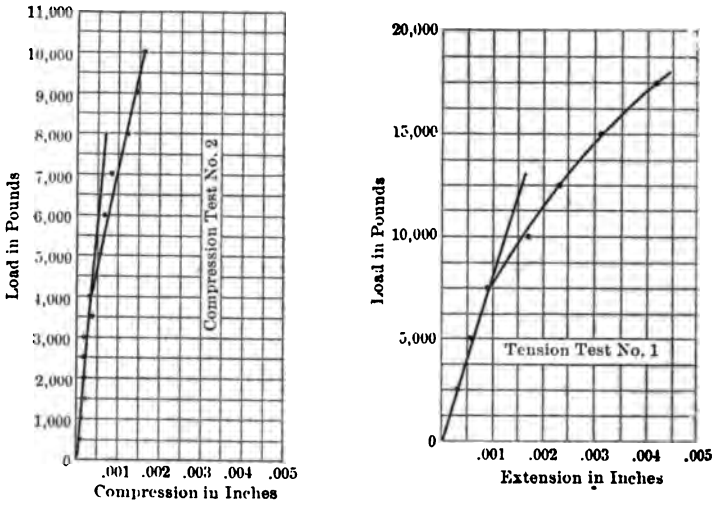


FIG. 19 RATE OF OPENING WITH INCREASE OF LOAD

The extensometer used, which was one devised by the offi in the materials testing laboratory of Columbia University, is cor ered more adaptable to measuring changes in the rate of stretch load than the exact stretch at any particular load. This is especi true with short specimens such as were used in these tests. this reason it is assumed that the modulus in compression tension are approximately equal, although it cannot be proved these tests.

For frames of these proportions, on the basis that the stres the material is proportional to the strain and that the modulu



FIGS. 21 AND 22 STRESS-STRAIN DIAGRAMS

elasticity in tension is identical with the modulus of elasticity compression, and assuming $n = \frac{1}{4}$, the analysis of Andrews Pearson results in the following formulation

$$S = \frac{W}{A}\left[\frac{L}{r\gamma_2}\left\{\frac{1}{\left(\frac{e}{r}\right)^{\frac{1}{2}}} - \gamma_1\right\} + 1\right]$$

where the notation is the same as that employed by Professor kins. Substituting the values applicable to these castings, it is fo that

$$S = 2.035\,W$$

Upon inspection of Fig. 18 it will be noted that casting No. 1 begins to change its rate of opening at some load between 2500 and 2750 lb. and accordingly the rate of stretch with load on the tensile test specimen is predicted to change at a load between 7100 lb. and 7800 lb. per sq. in. Reference to Fig. 22 will show that the change in the rate of stretch with load when the specimen was tested in tension took place at 7500 lb. per sq. in. Casting No. 2 begins to change at about 14,150 lb. per sq. in. Referring to Fig. 21 it is seen that the change in the rate of stretch in the specimen when tested in tension takes place at about 13,750 lb. per sq. in.

According to the formula usually applied to such cases the following results would be expected

$$S = \frac{Mc}{I} + \frac{W}{A}$$

in which the symbols are as used by Professor Jenkins. For the particular dimensions of these castings the formula may be written

$$S = 1.834\,W$$

For casting No. 1 this formula would indicate that for a tensile stress of 7500 lb. per sq. in. a load of 4100 lb. would be required, while for casting No. 2 in order that the tensile stress reach 13,750 lb. a load of 7500 lb. would be required. A comparison of the results of these analyses with the experimental results is sufficient proof of the accuracy of the Andrews and Pearson formula.

In regard to the statement made in Par. 5 relating to the value of Poisson's ratio, it will be found that a change in this ratio from 0.25 to 0.30 will not affect the result more than 3 per cent.

Because of the results of these few experiments and in view of the fact that Professor Jenkins' method of experimentation and analysis was not adapted to proving any theory of stress-strain relations, it is believed that the case against the Andrews and Pearson formula is not proved.

In conclusion, attention is called to the fact that the uncertain nature of cast iron and the impossibility of determining the effect of shrinkage stresses and imperfections in the casting involve a considerable element of doubt as to the proper working stress to be allowed, no matter what analysis of stress-strain relations is used. But these uncertainties do not justify the application of inaccurate formulae for the determination of the relation between load and maximum intensity of stress. In fact a more accurate analysis of the case as

seems to be given by the Andrews and Pearson formula tends to lessen the elements of uncertainty.

FRANK I. ELLIS. I have always felt, as have my associates who have had considerable experience on this line of work, that the relation of the ultimate strength of a curved cast-iron specimen to that of an attached test bar is a very difficult one to determine. We do not think anything can be gained by making sample curved sections such as carried out by the author of the paper, unless they are made full size. We have found that in comparing different-sized machines, for instance, one with a housing weighing approximately 9000 lb. against one with a housing weighing 40,000 lb., the relative values as compared with a test bar are not at all the same. We have made no special tests for several years, but carry out all our designing very much on the lines of the conclusion Professor Jenkins came to, that is, design the member from the formula given in those conclusions and then correct to suit our experience. In other words, we figure as closely as possible and then make a further allowance. We commonly use 2500 lb. and sometimes 2000 lb. per sq. in. as a safe value for cast iron for the tension side of all shear housings. On other work we run up in some cases as high as 4500 lb., but in such machines as vertical shears, we would not think of using anything higher than 2500 lb.

HENRY HESS. The real question at issue is not one of formula at all. What should be considered is the yield point, in other words the elastic limit. The real trouble is that the elastic limit of the material is seldom accurately known. There is now in existence a testing apparatus, probably not familiar to many, which makes it possible to recognize the absolute elastic limit of any structure in any material. This instrument is based on a law which is fairly well recognized but only recently embodied in practical instruments. This law states that deformation is accompanied by a rise in temperature and that such rise is very marked at the point of change of proportionality between stress and deformation. The instrument consists of a delicate pyrometer and a sensitive gold-leaf galvanometer and shows a sharp break in the recorded line when the elastic limit is reached. If the line starts at an inclination of 45 deg., the change in direction at the elastic limit is not gradual, but is an absolutely definite break to an inclination of say 30 deg. This eliminates all doubt as to the exact value of the elastic limit. The small pyrometer may be clamped in any convenient way to any portion of such structure.

The ordinary formulae will apply when there is substituted for the element of inaccuracy, the value of the material constant, absolutely definite knowledge of its value.

OBERLIN SMITH. In Fig. 23 herewith, which represents the outlines of a typical C-shaped beam such as is used in many forms of press frames, AA is the ram axis along which the pressure acts to force the ends of the beam apart and NN is the neutral axis. My usual practice has been to make the depth of the beam at DD, $D'D'$, and $D''D''$ such as to give equal strength on the line AA when calculated by the cantilever beam formula, with LL and $L'L'$ and $L''L''$ as the respective beam lengths. The breadth of these sub-beams, as they might be called, if uniform would be represented by BB in Fig.

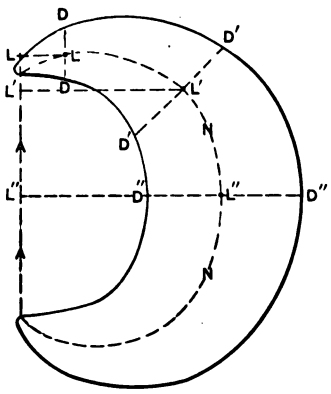


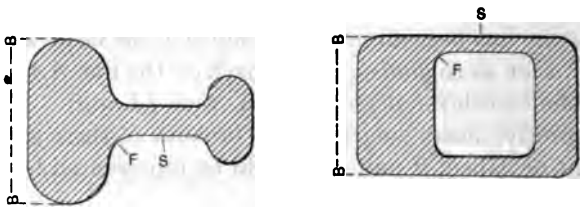
FIG. 23 TYPICAL C-SHAPED BEAM

24 or Fig. 25 and the formula would of course depend upon the shape of the cross section. If I am in error in this treatment of the subject I should be very glad to hear from others who have made a closer study of the matter.

There is a tendency in a beam of this kind for the web to split longitudinally, approximately on the neutral line, due to the tensile stress mentioned in connection with section AG of Fig. 8. The writer has had webs of presses split at S in Figs. 24 and 25 and somewhere along NN in Fig. 23.

There are many cross-sections for press frames, but the most usual are shown in Figs. 24 and 25. These are equally good as regards

resisting vertical stresses on the line AA (Fig. 23). In regard t
sional and lateral bending stresses, Fig. 25 has much the adva
Presses are frequently subjected to other than the normal v
stresses on account of large dies striking the work irregularly, pe
on one corner at a time, thus having a tendency to bend and
the frame of the machine. Obviously, no better shape than F
could be contrived for all these stresses and, furthermore, s



FIGS. 24 AND 25 COMMON FORMS OF PRESS FRAMES

form of machine is much more beautiful, as well as more soli
rugged in appearance. The form shown in Fig. 24, however, is in
general use, doubtless because it is cheaper to make, both as re
pattern-making and molding.

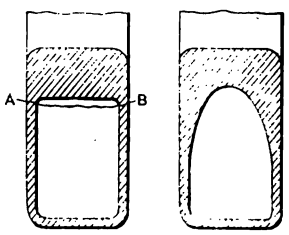


FIG. 26 SECTIONS OF PUNCH AND SHEAR FRAMES

In any case, the fillets shown at F (Figs. 24 and 25) shou
made very large to avoid cracking in cooling as is very likely to h
on account of the massive tensile member joining the much l
web.

WILFRED LEWIS. Thirty years ago punch and shear f
were made with a section as shown on the left of Fig. 26 herewit
they always split at AB. I came to the conclusion that the wea
in all such frames was in the web and I changed the form to th
the right of Fig. 26. I have never heard of a broken frame of th
tion.

There is no mystery about the breakage at AB, for if tension or compression is running in a given direction it cannot be deflected without putting a strain on the web, which must be strong enough to deflect these forces around the curve. The reason why curved beams do not develop their estimated strength is in my opinion simply due to the fact that no attention is paid to the section of web necessary to deflect the tensile stress in the flange.

THE AUTHOR. In Professor Rautenstrauch's tests of castings referred to in his discussion, deflection readings were taken, which when accurately plotted with a curve drawn through the points, show no sudden change in the proportionality between load and jaw opening; but in order to locate this point for comparison he uses two straight lines instead of a curve and, since it is possible to draw an infinite number of tangents and chords to a curve, he is able to get intersections anywhere he desires.

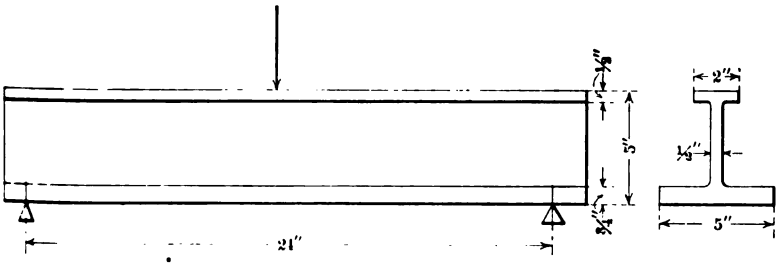


FIG. 29 I-BEAM USED FOR STUDYING RESISTANCE TO HORIZONTAL SHEAR

The lines he gives are in contradiction of such authorities on the elastic properties of cast iron as Kupffer,[1] Love,[1] Saint Venant,[1] and Professor Pearson,[1] as well as any well known authors on the strength of materials. Professor Pearson, who is responsible for the formula in question and should be satisfactory authority on this subject, states on p. 733 that "Hooke's law does not hold for cast iron even in the case of very small strains." Professor Morley states that the elastic limit of cast iron is almost at zero.

The I-beam shown in Fig. 29 was cast from the same heat as the curved specimens and was used in studying the resistance to horizontal shear. This specimen was tested as indicated in Fig. 29 and the autographic record is presented in Fig. 3', which in no way suggests a sudden change in the rate of deflection similar to that shown in Professor Rautenstrauch's diagrams.

[1] History of Elasticity, by Todhunter and Pearson, Vol. 2, Pt. 1.

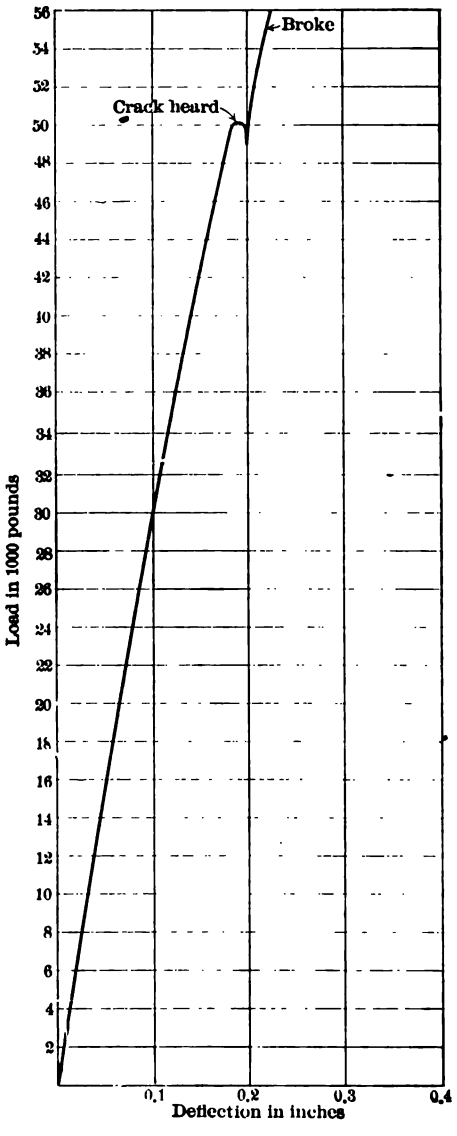


FIG. 30 FULL-SIZED AUTOGRAPHIC RECORD OF BEAM IN FIG. 3

The elastic laws for cast iron are given in Par. 32 and Par. when plotted show no point that will permit the use of Pr Rautenstrauch's method of analysis.

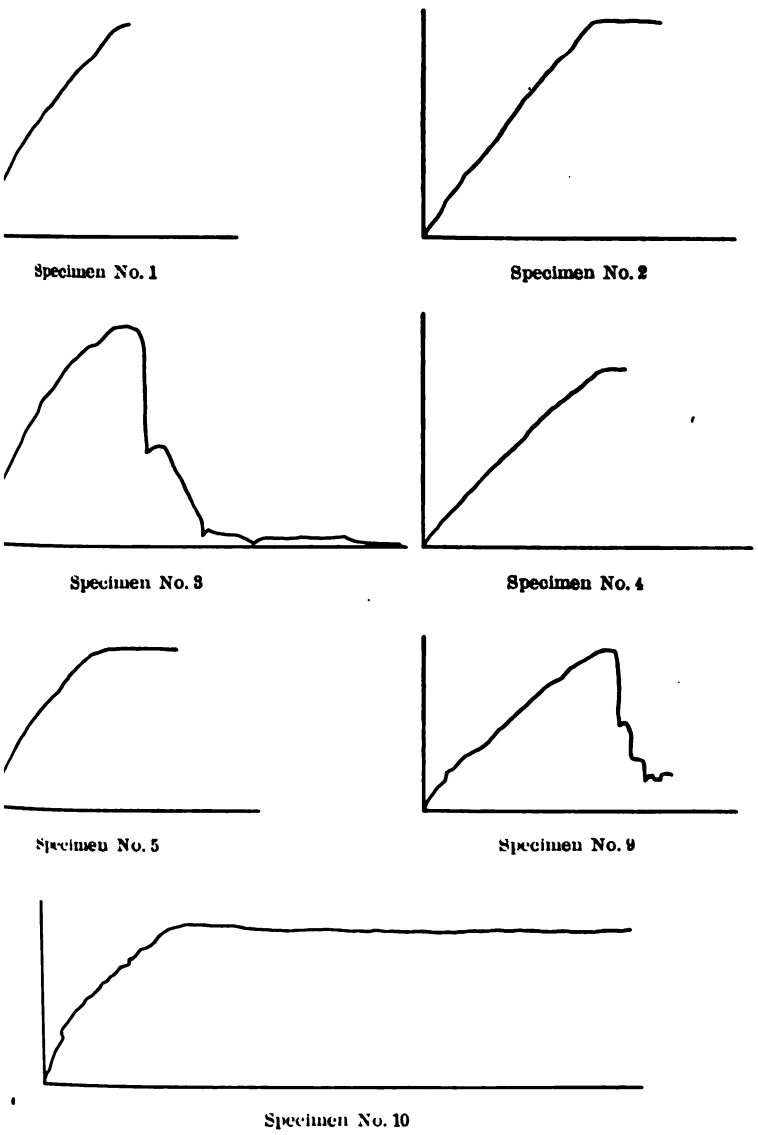


FIG. 31 AUTOGRAPHIC LOAD-DEFLECTION CURVES

The sudden change in the rate of stretch of his test bars is easily accounted for by the fact that they were stressed to that point in testing the casting, it being known that an artificial elastic limit can be given cast iron by previous loading.[1]

The curves shown in Fig. 31 were drawn by the autographic recorder and are undoubtedly more accurate than those given by Professor Rautenstrauch. They show no elastic limit or yield point, as stated in Par. 29.

It occurred to the author to use Professor Rautenstrauch's method of analysis, but investigation showed that it was not applicable to cast iron and had the following objections when used for steel:

a The formula applies only to specimens with curved spines.

b It is true only for one section of the specimen.

c The load-deflection curve gives the total deflection or the deflections of an infinite number of sections.

d The specimen may yield first at a section some distance from the one assumed by this method without detection.

e It is possible for a casting to yield in the straight portion similar to a straight cantilever beam while the calculation is made for a section in the bent portion, which would be quite erroneous.

From a theoretical standpoint there is no doubt about the accuracy of the Pearson-Andrews formula for stresses within the elastic limit of materials that obey Hooke's law; but it is not true for cast iron, even for the smallest loads. If someone should substitute the exponential or parabolic laws for Hooke's law in the formula, he would have reasons for his plea of defense when the formula is placed on trial.

It appears to the author that Professor Rautenstrauch's calculations based on the sudden change in the rate of stretch for cast iron, the existence of which is denied by the best authorities, and a formula based on an elastic law that is not true for cast iron, cannot be taken seriously. They were, moreover, applied to two test specimens only; neither of which failed in the section for which the formula he used is applicable. On page 586 of Volume 31 of Transactions, he states that "the formula has not as yet been sufficiently developed to determine its usefulness in establishing proportions for other than sections at right angles to the load." According to this statement the formula does not apply to his tests or

[1] Trans. Am.Soc.M.E., vol. 17, p. 694.

ast-iron specimens because the maximum stress did not occur in a ection at right angles to the load as is clearly shown by position f fracture.

The author infers that Mr. Hess, in his discussion, proposes that we should make a critical study of the elastic properties of cast iron and modify our formulae to suit the actual conditions, which is a point well worth considering. The testing apparatus he mentions is probably that described by Mr. E. Rasch in a paper before the Copenhagen meeting of the International Association for Testing Materials. The use of this method involves the coefficients of heat conductivity and radiation.

Fig. 32 shows the forces acting on a very small rectangle at the point A in Fig. 33. The normal forces tt are due to bending, whereas the forces s_v s_v are due to vertical shear. Now it is easily seen that these two sets of forces would cause the rectangle to rotate and it is necessary to introduce the forces s_h s_h to effect equilibrium. Hence, the horizontal shearing forces s_h s_h must always equal the vertical forces s_v s_v.

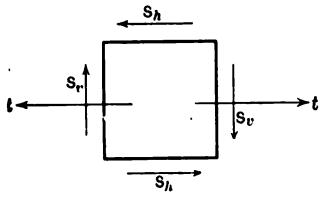


FIG. 32 FORCES ACTING AT A (FIG. 33)

The total vertical shear on the section x distance from the support, in Fig. 33, is

$$Q = \frac{dM}{dx}$$

which is the rate of change of the bending movement and is analogous to acceleration. The intensity of shear at any point in the section may be expressed by the equation

$$q = \frac{Q}{I\,z} \int_{y}^{y'} zydy$$

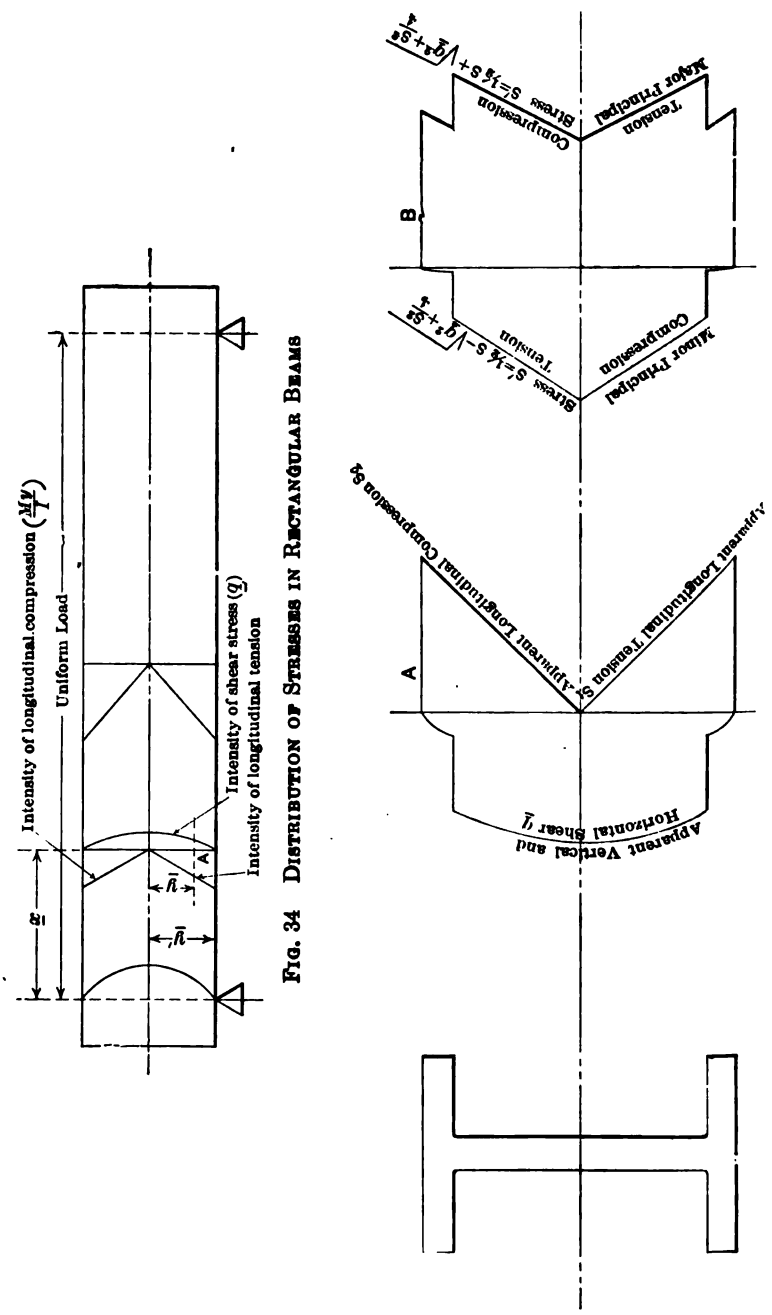


FIG. 34 DISTRIBUTION OF STRESSES IN RECTANGULAR BEAMS

where

q = unit shearing stress at y distance from the neutral axis
Q = total shear on section
z = breadth of section at y distance from neutral axis
I = moment of inertia

The normal stress at any point in the section is determined by the formula

$$S = \frac{My}{I}$$

An idea of how the apparent stresses S and q, are distributed over various sections of a rectangular beam may be gained from the diagrams given in Fig. 34.

The maximum resulting shear at any point due to the stresses S and q, is

$$q' = \sqrt{q^2 + \frac{S^2}{4}}$$

and makes an angle Θ with the neutral surface such that

$$\tan 2\,\Theta = \frac{S}{2q}$$

The principal unit stress at any point is

$$S' = \tfrac{1}{2} S \pm \sqrt{q^2 + \frac{S^2}{4}}$$

and makes an angle ϕ with the neutral surface such that

$$\tan 2\,\phi = -\frac{S}{2q}$$

The equivalent normal stress, namely, a linear stress that would produce a deformation equal to that actually produced by S and q is

$$S = \frac{(1-\lambda)}{2} + \frac{(1+\lambda)}{2}\sqrt{4q^2 + S^2}$$

where λ is Poisson's ratio.

Fig. 34 shows how the apparent and principal stresses are distributed over a section of an I-beam, diagram A showing the variation of the apparent stresses S and q and diagram B the variation of

the principal stresses S', the direction of which may be found a point by determining the value of ϕ. Diagram B shows how the at the juncture of the flange may be greater than the stress a outer fibre. The value of q' may also be sufficient to produce f

The step in the curve shown in Fig. 30 is due to internal caused by the principal stress.

The above discussion is applicable only to straight beam does not pertain to the spine of a curved beam because of the al of shear in that portion. This fact may be seen from the insp of Fig. 35, which represents a C-frame consisting of a solid b connecting the two straight beams A and B, which are made

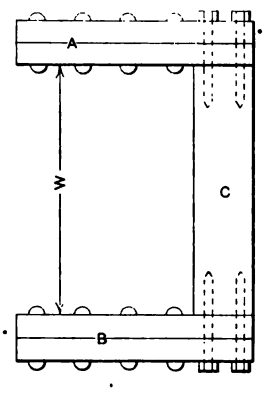


FIG. 35 C-FRAME SHOWING ABSENCE OF SHEAR IN C

pieces riveted together. The beams are subjected to vertic horizontal shear, and there exists a tendency to shear the ri them, but the piece C, although it may bend, is free from sh

In response to an inquiry[1] the author will state what matl ical points are taken into account in one formula and not other. They differ essentially as follows:

a The beam or Unwin formula merely considers the due to bending and the direct pull of the load and is on the same assumptions as the fundamental fc for straight beams.

b The Résal formula takes into consideration the stre to bending and the effect of curvature.

c The Pearson-Andrews formula considers the stress to bending and direct tension, the curvature and contraction.

They are all based on Hooke's law and Bernoulli's assumption, neither of which is true for cast iron. The assumption that these are true has been the source of weakness in all rational formulae for cast-iron beams, and all attempts to improve the formulae by basing them on the actual laws governing the properties have been futile owing to the mathematical complications involved.

Formulae 6 and 7 of the appendix are for castings having straight spines of rectangular cross-section. The value of K depends on the size of the casting, temperature of power, rate of cooling, and percentages of silicon and carbon. For the specimens tested it has a value of about 7.3.

[1]Dr. Sanford A. Moss

No. 1279

FINISHING STAYBOLTS AND STRAIGHT AND TAPER BOLTS FOR LOCOMOTIVES

By C. K. Lassiter,[1] Richmond, Va.

Non-Member.

The locomotive boiler of average size contains about 1500 staybolts, the number varying from 1200 in the smaller sizes to 2000 or more in the heavier types. They vary in length from 4½ in. to 10½ in. for the water-space bolts, which constitute about 75 per cent of the total number, to about 28 in. for the radial and crown bolts.

2 Probably no part of the boiler is subject to more destructive conditions than these little staybolts. The most serious strains are those due to expansion and contraction of the inner sheet, which bend the bolts and cause them to break close to the outer sheet. This is especially true of the side or water-space stays, which are comparatively short and have very little flexibility.

3 The material used is a high grade of refined iron, close-grained and tough. The pitch being very important on account of entering the second sheet, these stays were formerly cut to length from the bar, drilled for centers, and threaded on engine lathes. The center-drilling was not always concentric and considerable time was required to center the rough bolt so that a good thread could be obtained. This method proving too expensive, bolt cutters were used for the work, but the results were not entirely satisfactory. It was difficult to cut the threads full and smooth with one passage of the chasers and the second passage was taken at the sacrifice of pitch, as well as of time, because there was not enough material to remove to carry the chasers along properly. The introduction of the lead screw in bolt cutters brought about a very considerable improvement in pitch, but still there was trouble in getting the thread smooth for the reason

[1] Mechanical Superintendent, American Locomotive Co.

Presented at the Spring Meeting, Atlantic City 1910, of The American Society of Mechanical Engineers.

that the chasers were not always as accurate as the lead screw, which conditions the threads would be rough or torn.

4 About thirty years ago the idea was conceived of concavi bolts or reducing them in the center below the root of the tl the object being to provide flexibility to compensate for the e sion between the inner and the outer sheets. Laboratory tests sl that a bolt reduced in the center would withstand about tw many vibrations before breaking as one on which the thread left straight for the full length. For many years it was the ac practice to reduce a bolt in diameter on engine lathes after i threaded in the bolt cutter and drilled for centers. (Figs. 1 ar

5 In 1900, Alonzo Epright, an engineer in the employ Pennsylvania Railroad, designed machines which were fully

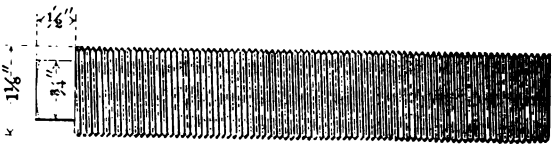


FIG. 1 SQUARE END WATER-SPACE STAY (PLAIN)

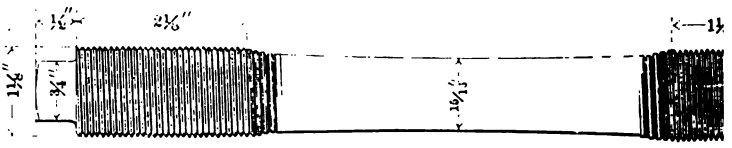


FIG. 2 SQUARE END WATER-SPACE STAY (CONCAVE)

matic in that they made from the bar, threaded and concav diameters of side stays up to 10 or 11 in. in length. author has no knowledge of the production of these machin therefore can make no comparison of costs.

6 The vertical type of machine for threading these bol used to some extent and it seemed that if the proper chaser co made the best results would be obtained from this type of m because the weight of the head would assist the chaser to g accurate pitch. In the horizontal or bolt cutter type the chase carry along the vise and carriage to the detriment of accuracy lead. Also, the flow of oil would assist in washing away the which were troublesome in the horizontal machine. Furthe

the vertical type of machine is more convenient to operate, one man attending six or eight spindles with ease.

7 After a great deal of experimenting a die head was developed in which, with chasers properly ground, the limit of accuracy of 0.01 in. in 8 in. can be maintained without the use of the lead screw, which is more nearly a perfect pitch than many staybolt taps in daily use. Where a proper lubricant is used a very fine, smooth thread can be obtained at a uniform cutting speed of 20 ft. per min.

8 The turning or reducing tools are shown in Fig. 3, the cutting points being visible at the center, back of the chasers. To these tools

FIG. 3 DIE HEAD FOR THREADING STAYBOLTS

are attached the crossheads *KK*, which are actuated by profilers or formers passing through the spaces *LL*, over which the head is drawn by the chaser, the staybolt acting as a lead screw.

9 The staybolt-threading machine is shown in Fig. 4. The several die heads are attached by small rods to straps passing over the pulleys on a shaft at the top of the machine. The operator grasps one of the strap handles with his right hand and, by the aid of the rotating

pulley over which the strap passes, raises the die head until it comes in contact with the bracket which closes the die. With his left hand he places the squared end of a staybolt in a holder underneath the die and allows the head to drop until the chasers begin to cut, when he moves to the next die head and repeats the operation. By the time he has placed all the heads in operation, the first bolt is finished, the die having dropped automatically when the threading was completed.

FIG. 4 STAYBOLT-THREADING AND REDUCING MACHINE, WITH SPECIAL GRINDER FOR CUTTING TOOLS

10 In Fig. 4, the die head at the right is shown raised sufficiently to insert the staybolt in place; the next at the left is just beginning to thread the bolt and the two other die heads are in still lower positions.

11 A comparison of costs by the two methods, taking a 7½-in. side stay as an average length, would be about as follows:

FORMER PRACTICE

in bolt cutter, usually taking two cuts at $0.20	$0.40
centers	0.22
or reducing on engine lathe	0.75
per hundred	$1.37

PRESENT PRACTICE

;, threaded the entire length or threaded and concaved for ses and lengths, per hundred	$0.13

average number of stays, a saving of labor cost of $18.60 is obtained with a minimum of rejected stays.

METHODS OF DRILLING STAYBOLTS

: telltale holes which are drilled in the staybolts have been of considerable expense and annoyance. Some railroads after the stays are placed in the boiler, with pneumatic . Under these conditions there is danger that the hole may itral. It often happens that the drill runs through into the e or is broken off in the hole. In either case it is necessary the bolts and put in others. Sometimes the holes are a vertical drilling machine before being placed in the boiler. the breakage of drills is very large, averaging about sixteen er, and each broken drill means a staybolt thrown away. automatic machine has been devised for drilling these re the stays are placed in the boiler. They are fed from a d automatically centered in position for the drill. When bored about one-third of the depth, the drill is withdrawn olt is carried forward in the turret mechanism which holds ond and a third drill, completing the hole. Each drill is naller than the preceding one, providing for a minimum of id a maximum of clearance of chips. The holes are of epth and in the center of the bolt. The average breakage hree or four drills to the boiler.

COMPARISON OF COSTS

the boiler, per hundred (to which should be added the cost placements)	$0.90
der drill press, per hundred (to which should be added cost ills and waste of material and labor)	0.45
the automatic machine, per hundred (with the minimum ber of broken drills and bolts destroyed)	0.12

METHODS OF FINISHING STRAIGHT AND TAPER BOLTS

14 The usual method of finishing straight and taper bolts for locomotives was to drill for centers, place in engine lathes, face under the head, turn the body taper, turn the part to be threaded straight and to proper size, face down the thread end to length and shape, leaving the center intact, test and file to accuracy, and cut off center point, after which the bolt is ready to be threaded in the bolt cutter and to have the hexagon head changed to any special shape desired.

15 About 1889, S. M. Vauclain, Mem.Am.Soc.M.E., designed and used a turning head in connection with a vertical machine for bolts up to 12 in. long. Under rights obtained from him the Pennsylvania Railroad placed an equipment of this kind in its Altoona shops and that is the only railroad known to the author using other than engine lathe methods in finishing bolts.

16 As a great many straight and taper bolts used in locomotives are 12 in. to 20 in. in length and even longer, it became necessary to design for this work a turning head which would handle taper bolts up to 18 or 20 in. in length and up to $1\frac{3}{4}$ in. diameter of thread, and straight bolts in any length up to 27 in. and up to $2\frac{1}{2}$ in. in diameter. It may be quite possible to go beyond these dimensions should the specifications require. These requirements have been met by a special machine of the vertical, multiple-spindle drill type, with which is used a special cutter head shown in Fig. 5. This head is the real or essential means of producing these bolts, either straight or taper and cylindrically true to the axis, the machine being simply a proper means of driving and feeding the bolt during the turning operation.

17 The cutter head consists of a retaining shell of cast iron, the bore of which must be round and straight; six segments, three of which are rigidly fastened to the shell, the other three having a limited amount of freedom and being fastened in place by a taper key with an adjusting screw located in the center of the radius with a bearing on the shell; and three blades, alternating with three guides, placed between the segments and backed up with taper keys and adjusting screws. The taper keys, in connection with a certain amount of taper on the blades and guides, have sufficient movement to provide for about one-eighth inch adjustment for re-grinding of the blades, or with the same amount on the guides, one-quarter inch in diameter of bolts. It will readily be seen that when an accurately ground plug gage of the size that it is desired to turn the bolt is placed centrally in the head, the blades and guides can be adjusted to their proper position. The three

ose segments are then forced forward by the taper key, clamping e blades and guides rigidly in their proper working position.

18 The economical use of this method of turning bolts, particu-ly in the railroad shops and locomotive works where taper bolts largely used, necessitates a change of system. The usual practice, ecially on repair work, has been to carry in stock only standard es of forgings, though in some cases the more common sizes were ced in stock finished. With the engine lathe located near the loco-

FIG. 5 CUTTER HEAD AND ATTACHMENTS

otive being repaired, the bolts were fitted to the hole after the least ssible amount of reaming had been done that would clean up the le.

19 The improved system contemplates the turning, facing under e head, and placing in stock of standard sizes in lengths of 6, 9, 12, 5, and 18 in. and varying in diameter under the head by thirty-seconds of an inch. Stock may be kept in sixty-fourths of an inch if esired, but very few holes will be found which require less than thirty-

seconds of an inch to clean up. In fact, the chief reason for carrying the intermediate sizes would be to save the hole when it cannot be cleaned up within the next thirty-second. Standard reamers are used, with collars or marks to indicate when they have been driven to the required depth. All bolts have standard hexagon heads conforming to the thread diameter. The sizes of stock are given in Table 1.

20 Bolts are specified with relation to the length and the diameter under the head, and the stock size next longest is used. Under these conditions not more than 3 in. must be cut off to bring the bolt to the proper length. The stock bolts are then taken to the bolt-altering machine, which is a quick-acting hand machine equipped with collet chucks and split bushings for the various diameters of the bolts. The end may be cut off to the proper length and turned for cotter pins, and the head changed to counter sink, box head, button head, or whatever may be required. After threading on the bolt cutter, the bolt is ready to drive in place without further fitting.

21 A comparison of costs by the two methods, taking a 1½ in. by 9 in. bolt as an average would be about as follows:

ENGINE LATHE PRACTICE

	Cost per hundred
Drilling for centers	$0.22
Turning in lathe	2.50
Altering in lathe	$2.50 to 3.50
Threading in bolt cutter	0.22
Cutting off center points	0.10

PRESENT PRACTICE

Pointing the blank	$0.12
Turning by the method described	0.41
Cutting off and changing points and heads where necessary on the bolt-altering machine	$0.40 to 0.60
Threading in the bolt cutter	0.22

22 A device is now being perfected by which the threading can be done automatically at the same time the turning is done. This not only eliminates the bolt cutter charge of $0.22 per hundred, but assures a full, uniform thread absolutely in line with the body of the bolt and square with the facing under the head. When used in connection with a nut faced squarely with its thread, the most satisfactory bolt is obtained.

23 A combined turning and threading device implies a modified form of the cutter head previously described, underneath which

TABLE 1 STOCK SIZES

G S THREADED DIAMETERS OF BOLTS AND 32 DIAMETERS UNDER THE HEAD

ameter.....	¼			⅜				1				1¼			
under head...	9/32	11/32	13/32	7/16	15/32	17/32	19/32	1 1/32	1 3/32	1 5/32	1 7/32	1 9/32	1 11/32	1 13/32	1 15/32	1 17/32
der head.....	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
	...	...	...	...	9	9	9	9	9	9	9	9	9	9	9	9
	...	...	...	...	...	...	...	...	...	...	12	12	12	12	12	12
	...	...	...	...	...	...	...	...	...	...	...	...	15	15	15	15
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	18	18

ameter.....	1½				1¾			1½				1¾			
nder head.....	1 17/32	1 19/32	1 21/32	1 11/16	1 23/32	1 25/32	1 27/32	1 13/16	1 29/32	1 31/32	1 1/32	1 3/32	1 29/32	1 31/32	1 1/32	1 3/32
der head.....	6	6	6	6	6	6	6	6	...	...	...	...	...	...	...	...
	9	9	9	9	9	9	9	9	...	...	...	...	...	...	...	...
	12	12	12	12	12	12	12	12	12	12	12	12	...	...	...	...
	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18

a die head of special construction. This die head is carried r more vertical rods or guides which are attached to a ring the cutter head is fastened. Provision is made for squaring ead with the cutter head at the time it begins cutting the ıd at the same time automatically placing the die head in a where it is free to move in a vertical plane up or down in portion to the difference between the feed and the pitch of d to be cut. An automatic knock-out is provided which die head and passes to one side, allowing the threaded through to any length within the feed of the machine ese conditions it will be seen that so long as the length of d to be cut is the same, the length of bolt to be turned is al. The device is very simple in its construction and does r a skilled mechanic to adjust or operate it.

No. 1280

ENGINES FOR DRIVING ALTERNATING-CURRENT GENERATIONS

H. G. Reist, Schenectady, N. Y.

Member of the Society

oblem of driving an alternating-current generator by means engine is not inherently different from that of driving it from engine. If the shaft of the engine turned with a uniform no difficulty would be experienced and no special design necessary. It is the variations in angular velocity and speed t the driving of alternators.

he current of a single generator is used for lights or for heat- electric furnaces or in electrolytic work, variations in ve- her during a single turn or due to the hunting of the governor ly increase and decrease the load as the speed varies. If motors are driven from a single generator, it is only under circumstances that any trouble is experienced due to speed s in the engine, because this type of motor is asynchronous not have to follow exactly; it is as if it were belted to the e connection being slightly flexible.

ynchronous motor or rotary converter, on the other hand, p in phase and behave as though geared to the engine, and pond to all its speed variations. If it does not keep abso- en, that is, if its phase relations change, cross-currents will hen two or more generators are operated in parallel, their is similar, any angular departure of one from the other cross-current. The volume of the cross-current depends, given design of generator, on the angular departure of the s from each other. This departure may be twice the angu- tion of the engine rotating parts from a mean position, be- e may be a maximum distance ahead while the other is in backward position.

d at the Spring Meeting, Atlantic City 1910, of The American f Mechanical Engineers.

4 If the generators were mounted on the shaft so that the relations of the poles to the cranks were identical, and if it were possible so to synchronize them that the corresponding cranks of engines to be run together were exactly together, no cross-currents would flow, because the engines would slow down and speed up together. This is not feasible, however, and it becomes necessary to design the engine so that it will to run with a fairly uniform rotation. It has been found good practice to limit the variation from a mean position of the revolving parts of the electric generator to $1\frac{1}{4}$ electrical degrees.

5 An electrical degree is $\frac{1}{360}$ part of the space occupied by two poles on a generator; that is, a two-pole generator is the unit and an electrical degree is one mechanical degree of such a machine; if the generator has four poles, an electrical degree will be one-half a mechanical degree of the circle on which the poles are mounted; if there are 6 poles, it will be one-third of a mechanical degree. In general, to reduce electrical degrees to mechanical degrees, we must divide the allowable variation by one-half the total number of poles on the generator; so that the $1\frac{1}{4}$ electrical degrees mentioned above for a 20-pole machine would be 0.125 actual degrees on the circumference of the flywheel. From this it is evident that with a generator of many poles, a more even speed is needed than for one with few poles. For a 60-cycle generator, which at a given engine speed has $\frac{60}{25}$ as many poles as a 25-cycle generator, the evenness of running must be much greater than for a 25-cycle generator.

6 The cross-currents between two electrical generators tend to speed up the lagging machine, bringing them more closely into synchronism. If there were no inertia the rotating parts of generator and flywheel would quickly get into synchronism, reducing and almost eliminating the cross-currents. This is, however, an ideal condition. The cross-currents are a factor of the amount of inertia with a given natural angular variation, and it will readily be seen that from this standpoint the larger the flywheel the less effect a given value of currents or torque will have on the mass. If the flywheel is very large, the currents which it may be practical to allow to flow between the machines may not be able to draw them together at all. Hence a large flywheel, while useful in obtaining uniform rotation, so far as the engine is concerned, prevents the current flowing between the machines from being very effective in drawing them into synchronism. This shows that it is desirable to obtain uniform rotation in other ways than by the use of an excessively heavy flywheel. Currents flowing between machines occasion losses in the copper and this

adds to the heating of the machine. They thus reduce the output with a given rise of temperature and reduce the efficiency.

7 Certain elements of design may be introduced into an electrical generator to make it less sensitive to slight variations in turning moment supplied by the engine, such as building a generator of poor regulation. The regulation must not be too poor, however; otherwise the operation of the system will be unsatisfactory. A "squirrel-cage" winding in the poles of the generator allows secondary currents to flow in this part of the structure and increase the torque, tending to draw the generators together with a given interchange of current between the two machines. This is of great assistance in parallel operation of generators and should generally be applied on generators to be driven by gas engines. If a flexible connection could be provided between engine and generator it would greatly assist in satisfactory parallel operation, but this connection is generally applicable only on small machines. The ultimate solution lies in the direction of greater uniformity of motion in the engine itself.

8 Uniformity of rotation of gas engines is dependent on a number of elements of design, such as (*a*) the number of impulses per revolution, which in turn is dependent on the number of cylinders and arrangement of cranks and on whether a two or a four-cycle system is used; (*b*) the compression and weight of the reciprocating parts; (*c*) the time of ignition; (*d*) the weight of the flywheel. The use of a heavy flywheel, however, while one of the simplest, is the least desirable method of obtaining even rotation of the engine shaft, and other means should be used to obtain as uniform rotation as possible.

9 The following seem to be the desirable characteristics of gas engines for driving alternators:

a High speed. This will require fewer poles with a given frequency and a greater angular variation will be allowable.

b A light flywheel. This will allow the current to keep the generators together with a minimum disturbance.

c Large engines should be built with many cylinders and cranks so placed as to contribute to an even turning moment.

DISCUSSION

P. M. LINCOLN. I am obliged to take issue with Mr. Reist on one of the most important conclusions in his paper, that contained in Par. 6, in which he states that "if there were no inertia, the rotating parts of generator and flywheel would quickly get into synchronism,

reducing and almost eliminating the cross-currents." The truth of this statement depends entirely upon the definition of cross-currents. It is usually understood that if the flow of energy from all of the alternating-current units in parallel is not essentially the same at all times there are said to be cross-currents. If this definition is accepted, Mr. Reist's statement is entirely unfounded. It is obvious that the flow of energy from a gas engine or any reciprocating engine is not uniform. There are some instances when it is a maximum, others when it is a minimum and in some cases it is even a minus quantity, as for instance when compression is taking place. If there were no inertia in the gas engine the flow of energy from the alternator into the circuit would be just as uneven and differ just as much from the uniform flow as the generation of this power within the cylinders. The fact that a gas-engine-alternator combination possesses inertia introduces another element into the energy flow equation. With inertia the rate that energy flows into the circuit is equal to its rate of generation minus its rate of storage in the reciprocating and rotating parts. By designing these parts properly the flow of energy into the circuit can be made much more uniform than its rate of generation. If gas engines and their generators could be built without inertia the condition that would then obtain would be far from ideal, as Mr. Reist states. In fact, the phenomenon which we know as cross-currents would be much larger if inertia were entirely absent than in the ordinary cases with which we have to deal.

Mr. Reist also makes the following statement with which I cannot agree: "If the flywheel is very large the currents which it may be practical to allow to flow between the machines may not be able to draw them together at all." While this may be true as an isolated statement, it has no bearing upon the problem in hand. With very large flywheels there would be no occasion for large currents to flow between the various units in parallel. In general, the larger the flywheel the more uniform will be the rotation and therefore the more uniform the flow of energy from that combination as compared with its rate of generation. Hence what we know as cross-currents will be reduced to a minimum.

There is one very important element in parallel operation of alternators which Mr. Reist neglected to mention. If any generator is displaced from its normal position in its magnetic field, a force equivalent to a spring at once acts to return it to the normal position. The greater the departure from normal position the greater will be the force acting to return it. Any mass which contains such

an element has a natural period of vibration. In the combination of alternator and engine the natural period of vibration will depend upon the inertia of the moving parts and the electrical and magnetic characteristics of the generator. If the impulses imparted to this mass by the engine are in resonance with the natural period of vibration, a state of affairs will exist which makes it very difficult and sometimes impossible to operate alternators in parallel. It is exceedingly important, therefore, in designing gas engines and the connected alternators to make sure that the natural period of vibration of the rotating parts of the combination is not in resonance with the impulses which may be imparted by the gas engine.

Another thing which Mr. Reist neglects to mention is the possibility of missing engine power strokes. It is usual to design flywheels on gas engines so that the departure from uniform rotation will not be excessive even when a power stroke of the gas engine is missed. It is evident that if the flywheels are made large enough to take care of this contingency there will be more than ample capacity when the explosions are taking place uniformly. So long as normal conditions obtain, that is uniform explosion, the normal operation of gas engines in parallel is usually better than that of steam engines in parallel.

THE AUTHOR. Mr. Lincoln's criticism regarding cross-currents on generators is apparently a matter of definition. Cross-currents flow between generators from a number of causes, such, for instance, as the difference in wave shape of the several machines, or differences in excitation and currents flowing between the generators due to the generators being out of phase. The first two are so-called wattless currents and the last is energy current. This is the class of cross-currents to which I had reference in my paper. It does not seem to me that the fact that the flow of energy from the engines is not uniform would necessarily establish cross-currents between the machines. It would simply mean that as a generator runs more slowly it gives up less power to the system than when running faster.

I agree with Mr. Lincoln that in general the larger the flywheel with any given engine the more uniform will be the rotation, yet I believe it is also true that if there is any tendency for the sets to hunt, the larger the flywheel the greater will be the cross-current that will flow between the machines and the greater will be the electrical disturbances. The natural period of vibration must be avoided in the design of the flywheel and it must be large enough so that the missing of a power stroke is not serious. These difficulties may, however, be

corrected by having many cylinders and thus more impulses p revolution, as well as by having a heavy flywheel. In respect to t point under discussion, I would consider that engine the best whic with a given degree of variation from uniform velocity during a given revolution, uses the lightest flywheel.

No. 1281

OPERATING EXPERIENCES WITH A BLAST FURNACE GAS POWER PLANT

By Heinrich J. Freyn, Chicago, Ill.

Member of the Society

The use of blast furnace gas engines in this country was first undertaken in 1902 by the Lackawanna Steel Company at Buffalo, followed four years later by the United States Steel Corporation in several of its plants. The import of the problem of utilizing the surplus gas may be realized by considering that eleven million tons of pig iron were produced in 1909 by the United States Steel Corporation, and that for each ton of iron made per day, 25 b.h.p. is available for purposes outside of the power requirements of the blast furnaces, provided this power is itself produced in gas engines. If, therefore, all the blast furnaces of the corporation were blown by gas blowing-engines and all other furnace requirements furnished by gas-electric engines, 750,000 b.h.p. would be available for other purposes.

2 In 1907 there were installed at one of the largest steel plants in this country, four Allis-Chalmers double-acting, four-cycle, twin tandem gas engines, gas cylinders, 42-in. diameter, 54-in. stroke, operating 2000-kw., 25-cycle, 3-phase, 2200-volt, alternating-current generators at 83.3 r.p.m. This addition to the existing steam-electric equipment was completed in 1908 and the electric power produced by these gas engines is used for electric-driven rolling mills and general light and power purposes. The gas-driven generators operate parallel with the adjacent steam units and with other gas-driven generators located 20 miles away.

3 The gas engine plant under discussion has been in regular service for one and one-half years, during which period the experiences and results described in the following pages were obtained.[1] These

[1]These experiences and records were compiled with the able assistance of Chas. C. Sampson, Mem.Am.Soc.M.E.

Presented at the Spring Meeting, Atlantic City, 1910, of The American Society of Mechanical Engineers.

were not gathered from the indications of one single experiment, or of a series of carefully prepared and conducted tests, but represent the average results of daily observations extending over one year's time. Since the degree of correctness depends on the accuracy of observation and care in recording the results of persons having various degrees of practical and technical training, inaccuracies entailing puzzling inconsistencies may have crept in and the data presented may not in every instance withstand the test of searching criticism; nevertheless it is believed that such information, derived from actual operation, will prove of more interest to the engineering profession than unassailable data obtained under test conditions.

4 The gas supply for the operation of all the gas engines of the plant is taken from six blast furnaces, all of which in 1909 were blown by steam blowing-engines, while the electric power for the plant was derived from both steam and gas-driven generators. This plant is therefore a so-called "mixed" plant, so far as the generation of power is concerned.

5 The quantity of blast furnace gas available for the operation of gas engines was therefore considerably less than when four of these furnaces are blown by gas blowing-engines. Because of the general business depression at the beginning of 1909, only three, and in the months of March and April only two, furnaces were in blast. Normal conditions were resumed about May or June, while all six furnaces were in blast during the months of September and October only.

CONDITIONS OF INSTALLATION

6 The gas power station in question was conceived in 1905, and all preliminary calculations relative to the amount of gas available for operating gas engines were naturally based on the conditions existing at that time, making the proper deductions for reduced gas production due to furnaces being out of blast for relining. Careful investigations showed that in 1906, 10 per cent of the total gas produced by six blast furnaces, equivalent to 10,200 kw., was available for use in gas-electric engines. The installation of 8000 kw. in gas engines seemed therefore fully warranted, particularly as it was expected that two gas blowing-engines simultaneously ordered would be in operation after November 1907, in which case the gas surplus, even with only five furnaces in blast (one furnace down for relining) would have been more than ample for the operation of four 2000-kw. gas-electric units. It could not be foreseen that business conditions

would change so radically in 1908, nor that the two gas blowing-engines would be so delayed, that for three years the saving of gas, which would have materially improved conditions for the electric units, could not be realized.

7 While the logical way to begin would have been with the installation of a number of gas blowing-engines, instead of first taking gas-electric engines in operation, increasing instead of reducing the available quantity of blast-furnace gas, such a procedure was impossible because of the immediate demand for increased electric power created by the installation of new electrically operated mills, as well as on account of local conditions of steam supply for the furnaces, which at that time prohibited the removal of a large boiler house, now occupied by the new gas blowing-engines. From the circumstances, however, that gas-electric engines were installed before any gas blowing-engine equipment existed, and that this power plant, as it so happened, had to be operated for almost two years under the most unfavorable and exacting conditions, a great deal of most valuable experience was gained, in that it was found that such a power plant could be maintained in operation—although with interruptions—with only two furnaces, and for a short period even with only one furnace in blast.

OUTPUT OF POWER PLANT

8 In Appendix No. 1, Table 2 shows the average kilowatt-hour produced by the gas power plant for each month of 1909, from which it appears that the average for the year was 5760 kw-hr., or 72 per cent of the total capacity of the plant, and this average for various months varied from 66.5% to 74% with two furnaces, 61.5% to 80.5% with three, 69% for four, 64% to 82.5% with five, 68.5% to 78% with six furnaces in blast. While during the first few months the number of furnaces in blast was very limited, the total output of the station was nevertheless not affected very materially. In fact, in the month of March, when only furnaces No. 1 and No. 2 were in blast, 74% of the total capacity of the plant was produced, a higher figure than the average output of the plant for the whole year.

SHUTDOWNS AND TIME LOST IN OPERATION

9 A record is being kept as correctly as practicable of all shutdowns and their causes. Table 3, in Appendix No. 1, gives the monthly averages, as well as the percentages of operating time and of time lost chargeable to the engines, and due to outside causes. The

power station is considered in this table as one unit, and the figures are averages applying to the four engines.

10 In Appendix No. 1, Table 2 gives the average monthly operating time of the station for the whole year, from which it appears that the average for the year was 77% of the total possible time, 14.2 % and 8.8% being the percentages of the time lost due to engine repairs and to outside causes beyond control. The respective figures for the first four months of the year show that the operating time from January to April was much lower than during the rest of the year, the lowest figure being 57% in January. However, the month of March with 71% shows again the noteworthy fact that with only two furnaces in blast the operating time was higher than the average for the first half of the year. This was made possible only by shutting off the boiler houses almost entirely. With the boiler houses off, blast furnace No. 1 made more gas than the gas engines, the stoves and one small boiler house could use, so that one bleeder at the furnace had to be kept open. During casting periods the engines were operated on the gas tank. In this manner operation was kept up for one whole week. The time lost chargeable to the engines is considerable for the first four months, due to the fact that owing to the uncertainty of sufficient gas supply under the existing conditions of furnace operation certain repairs and alterations were made on the engines, which otherwise would have been distributed over a longer period of time. It is to be noted that any time lost is rigorously charged against the engines if the latter for any reason are not ready to resume operation at any moment.

11 The time lost due to outside causes was particularly heavy in the first four months of the year, varying from 11½% in April to 19½% in February. In the records the lost time chargeable to outside causes is subdivided into losses due to operation of the plant, such as line troubles, or output not required, etc.; and losses due to lack of gas. This particular information is given in Table 4, Appendix 1, wherein the plant is again considered as one unit. Shortage of gas was responsible to the greatest extent for lost time from outside causes in the first four months of the year. In January this figure was as high as 94.5%, and while the average for the first half of 1909 exceeds 60%, the corresponding figure for the second half of 1909 is only 3%.

CONSIDERATIONS OF SAFETY WHEN THERE IS SHORTAGE OF GAS

12 Although the difficulties which were experienced in this period by the frequent inability of the blast furnaces to supply sufficient gas

to maintain operation of the whole plant, without heavily firing coal under the boilers, had no serious effect on the gas power plant, one important question was in the minds of all during this period, namely the safety of the installation. Antedating only a few months this period of gas shortage, a serious accident had happened at another plant where through lack of gas while only one furnace was in blast, the preliminary cleaning plant, the gas holder and parts of the pipe line conveying gas to the engines, exploded with disastrous effect. This accident caused a great deal of uneasiness and alarm in other gas-engine plants where several furnaces were out of blast.

13 A gas power plant is endangered in two ways by lack of gas, either from collapsing of the gas holder bell or from explosion. In modern gas-cleaning installations, the so-called secondary washing plant, which refines the gas for use in engines, is usually equipped with some kind of rotary washers. Certain washers of this type, such as the Theisen, can give a vacuum of 3 in. of water, and a discharge pressure from 8 in. to 10 in. higher than the positive or negative pressure on the suction side. The washers deliver the gas to a gas holder under variable pressure dependent upon the raw gas pressure, while it is the principal object of the gas holder to maintain a constant gas pressure at the gas engines, irrespective of what the pressure at the blast furnaces or in the gas-cleaning plant happens to be. As long as the pressure of the gas, and therefore its quantity, is sufficient to allow the rotary washers to keep the gas-holder bell floating; in other words as long as balance exists between the demand for gas on the part of the engines and the supply from the furnaces, there is no danger to the installation.

14 If the gas supply falls below the demand, the volume of gas in the holder will cover the shortage within the limit of its capacity and until the bell, descending completely, rests on its landing beams. The rotary gas washers will then continue to operate, creating a depression in the gas conduits by which they are connected to the gas main at the furnaces. The latter is virtually a large gas receiver into which all blast furnaces discharge their gas, and which in turn supplies the hot-blast stoves, the boilers, and the gas-cleaning plant. The vacuum created by the rotary washers will naturally be communicated to this main gas flue, but cannot be maintained as the overheard flue is connected with the atmosphere through hot-blast stoves and boiler stacks. Air will therefore rush into this flue and into the gas-cleaning plant and be drawn into the rotary washers together with whatever gas is supplied, and discharged into the gas holder.

As long as these conditions exist, the gas-holder bell is not in danger of collapsing, but there is imminent danger from explosion to the whole plant. Rotary gas washers do not discriminate between gas and air, and continue to operate, filling all gas flues, gas holder and engine connections with a mixture of gas and air which under certain conditions is highly explosive. Should backfiring occur in the gas engines when receiving a mixture of gas and air instead of pure gas; that is, should the fresh incoming charge accidentally be ignited, consequences would be as prompt as disastrous —the air and gas mixture in the pipe system would explode, possibly wrecking the whole installation by a series of explosions.

15 This is precisely what did happen in the accident mentioned, and profiting by this experience steps were taken to prevent the occurrence of such an accident at the plant under discussion. Power house, gas-washing plant and blast furnace office were connected by two independent telephone lines, and recording instruments, in addition to ordinary U-tubes, were installed in the washer building and at the blast furnace office, so that not only may the gas pressure be observed at any time, but it is automatically recorded for each period of 24 hours. Moreover an automatic alarm was installed at the blast furnace office, which rings a bell as soon as the gas pressure in the raw gas descends below a certain danger point, and whistle signals operated by solenoids from the blast furnace office were provided in the boiler house to inform the head fireman of the number of boilers to be "taken off" or put on gas. In addition an automatic bell was placed in this boiler house, calling the operators' attention to any drop below normal in the gas pressure.

16 Independently of the blast furnace department, the gas-cleaning plant operators were also carefully watching the gas pressure. The position of the gas-holder bell was made visible at any time by a system of incandescent lamps in the washerhouse, and strict orders regarding the use of the gas were issued by the blast furnace superintendent, instructing the men to favor the gas engines under any circumstances, as it was fully recognized that having taken care of the requirements of the hot-blast stoves, the remaining gas could not possibly be more efficiently utilized than in the gas engines. The practice was to shut off the gas immediately at a certain number of gas-fired boilers, as soon as the pressure in the overhead gas flue dropped below a predetermined point. Additional boilers were taken off if the gas pressure did not recover, so that sometimes as many as 24 boilers were being fired by coal exclusively. If this did not have

the desired result, stoves were taken off for short periods to increase the gas pressure above the danger point. At last, if all these steps did not improve the situation, one or more gas engines were shut down.

17 Fortunately in the majority of cases the blast furnace operators know in advance if the gas supply is likely to fail, and communication could easily be established to warn the departments concerned of the impending gas shortage. The diagram, Fig. 1, plotted from a

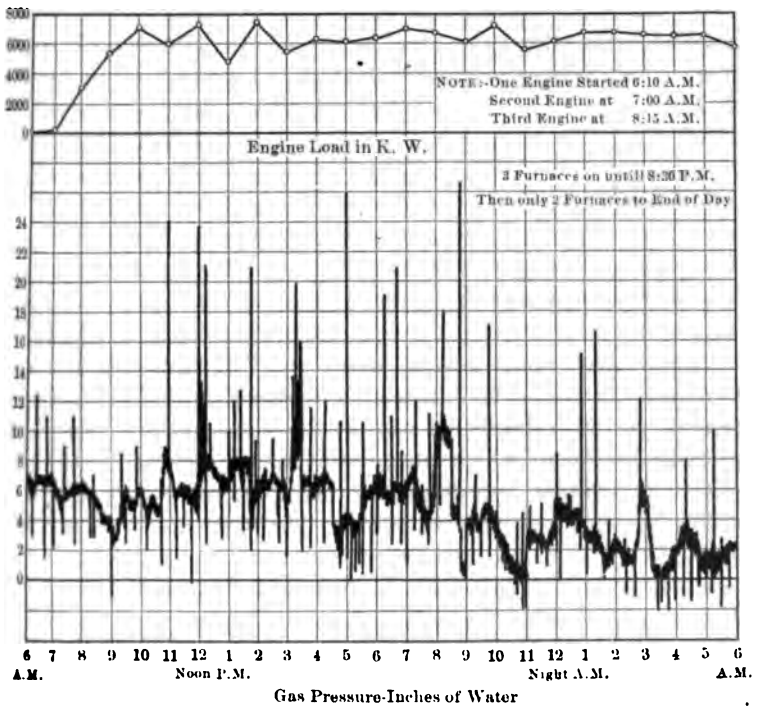


FIG. 1 DIAGRAM PLOTTED FROM BRISTOL CHART SHOWING GAS PRESSURE WHERE THE GAS ENTERS THE GAS-CLEANING PLANT

Bristol chart representing a 24-hour record of the gas pressure at the point where the gas enters the gas-cleaning plant, is a good illustration of the conditions existing on many occasions.

18 The system of close observation and of coöperation among the departments concerned worked to perfection, but nevertheless conditions existed at times which with all due optimism had to be called dangerous. It was frequently necessary to keep several gas engines running, with the gas pressure dropping below the danger point

momentarily or even for periods of a few minutes. This was unavoid able if the operation of certain departments dependent upon a suppl of electric power was to be maintained with any regularity. If the ga engines had been shut down every time a momentary drop in pressur occurred, it would often have meant an endless amount of shuttin down and starting of engines, altogether too frequent for satisfactor operation of the mills, and physically impossible for the gas engin operators.

19 The question whether an automatic safety device should b installed at the power plant under discussion was thoroughly consider ed and such devices were investigated; but it was decided that the in stallation of costly safety appliances, which were certain to becom inoperative with the normal number of furnaces in blast, was no warranted, as the conditions of gas shortage were exceptional and o temporary nature only. Besides, automatic safety devices, no matte how ingeniously designed, are never "fool proof," and have the rep utation of operating without cause and of failing to act when needed A further drawback is the tendency to over-confidence in the infalli bility of a safety device. In this respect gas-cleaning plants shoul be classed with boiler plants, where the "human element" cannot be eliminated, and safety depends ultimately upon the rigid enforce ment of certain established regulations. Responsible operators ca use good judgment which automatic safety devices do not posses to decide whether shutdowns are necessary when low gas pressur occurs, possibly for a moment only. This was proved time and tim again at the plant under discussion.

20 If such safety devices are considered necessary, however, th arrangement of automatic circuit breakers to shut off the power at th rotary washers, and simultaneously interrupt the ignition circuit o the gas engines, is decidedly better for safeguarding the plant than th installation of butterfly or check valves between rotary washers an gas holder, which shut off delivery under the control of the gas pre sure. While in both cases the aspiration of air by the rotary washe is effectively prevented, the former device protects not only the ga cleaning plant but also the gas holder, while the latter may cau collapsing of the holder bell by isolating it from the gas supply.

QUANTITY AND QUALITY OF GAS SUPPLIED TO ENGINES

21 The amount of gas produced by each blast furnace is calculate and distributed in proper proportion among the different places o its consumption. Monthly gas-distribution sheets give a record o

e average daily tonnage of each furnace, the kind of blast, whether ıtural or dry, the kind of coke used and the coke consumption per n of iron; further, the average gas analysis for each furnace based daily determinations of continuous 24-hour samples, the heat value r cubic foot at 62 deg. fahr. and including the sensible heat of the ; at 500 deg. fahr., the temperature of the air at the blowing engines, : number of cubic feet of air blown per minute, and the average ıst pressure. From these data the quantity of gas produced by :h furnace per minute is calculated according to methods given in pendix No. 2. The distribution of the gas from one blast furnace ;ed on such calculations is given in the accompanying table (Table erewith), reproduced from data given in Appendix No. 2.

TABLE 1 DISTRIBUTION OF GAS FROM BLAST FURNACE NO. 6
August 1909

	Million B.t.u.	Per Cent
l gas generated	324.1	100
·s and leakage	130.0	40
ring engines	92.1	28.4
l at furnace	9.0	2.8
ilaries	4.6	1.4
l used for blast furnace operation	235.7	72.6
l. surplus for furnace	88.4	27.4
p. equivalent of surplus	1470	

22 An excellent practical indicator of the gas quantity available engine operation is the gas pressure at the cleaning plant. With ore than three furnaces in blast the pressure is always sufficiently gh to make operation of the gas power station perfectly safe. Fig. shows the average monthly gas pressure at the main water seal

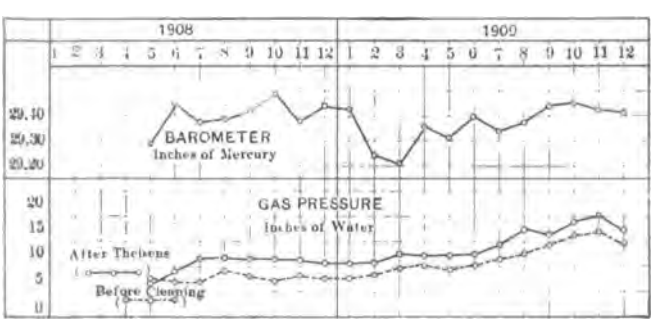


FIG. 2 GAS PRESSURE CURVES—BAROMETRIC PRESSURE (MONTHLY AVERAGES)

where the gas enters the cleaning plant and in the fine gas mi
the secondary washers.

23 While the quantity of blast furnace gas was subjected
siderable variation due to the generally unfavorable conditio
existed in the early part of 1909, the quality of the gas was al
to vary materially, so far as its chemical composition and he
were concerned. These were influenced not only by change
furnace burden and by the kind of product, whether basic iro
mer iron, spiegeleisen or ferrosilicon, but by other causes t
variations frequently recorded from hour to hour, could, tc
extent, be traced. The blast furnaces discharge their gas
common overhead gas main supplying stoves, boiler houses
engines. The intake for the gas-cleaning plant is located betw
naces No. 2 and No. 3, dividing the total length of the overh
in the proportion of one to two, approximately. In view of t
tral location of the intake nozzle it was expected that by mi
gas from these furnaces a fairly uniform quality, represen
average of all six furnaces, would be obtained for engine op
Due to the location of the boiler houses, however, this unifo
mixture could not be realized.

24 Fig. 3 shows the existing conditions previous to May 1
before the boiler plant for four blast furnaces was abandoned
to make room for the new gas blowing-engine house. The ta
stacks caused a flow of gas from furnaces No. 1 and No. 2 to t
house situated at the west end of the flue, while the gas fr
naces Nos. 4, 5 and 6 went to two large boiler houses locate
opposite extremity. The gas-cleaning plant received, therefore
exclusively gas from furnaces No. 2 and No. 3 or from No.
while No. 2 was out of blast. This was proved beyond any d
frequently comparing the chemical analysis of the gas delivere
power station with the analyses of the gas of the individual f

25 Thus for the month of June 1908 the average compo
the gas from blast furnaces Nos. 1, 3 and 4, which are in close
ity to the gas-cleaning plant intake, was as follows (blast furn
2 being out of blast and blast furnace No. 4 on spiegel):

Blast furnace No.	CO_2	CO	H	$\frac{CO}{CO_2}$
1.....	13.5	25.0	3.4	1.85
3.....	12.4	26.7	3.2	2.15
4.....	5.1	32.1	3.3	6.30

FOLDER No. 3

The average composition of the gas at the power station for the same period was:

CO_2	CO	H	$\frac{CO}{CO_2}$	B.t.u.
12.6	26.64	3.2	2.33	96.73

The analyses of the gas of blast furnace No. 3 and the gas at the power house, coincide very closely, establishing proof that during this time this one furnace was furnishing the gas for the engines almost exclusively.

26 Since abandoning the boiler house for blast furnaces Nos. 1 to 4, which now receive steam through a 14-in. steam line from the boiler house at the east end, all gas from furnaces Nos. 1, 2 and 3 is being delivered to the gas-cleaning plant, with the exception of a small portion which goes to a small boiler house at the west end, while the gas of the remainder of the furnaces flows in the same direction to the boiler houses of furnaces Nos. 5 and 6 and the electric station. To illustrate the present condition of gas distribution, comparative data were compiled, given in Tables 7 and 8, Appendix 2, which give the averages of gas analyses and heat values of the individual six furnaces, all of which were in blast in September 1909, and the average composition of mixtures of the gas from various furnaces calculated from the former. For the same month when these averages were taken the average composition and heat value of the gas delivered at the power house were:

CO_2	CO	H	$\frac{CO}{CO_2}$	B.t.u.
10.03	29.80	3.77	2.98	108.70

Comparing this analysis with the mixture characteristics, given in Table 8, Appendix 2, the gas appears to be most nearly equivalent to the mixture from furnaces Nos. 1, 2 and 3 together.

27 Conditions were decidedly better in the second half of 1909, so far as uniformity of the gas supplied to the engines is concerned, but it is easily seen that changes in furnace operation must even under present conditions affect the quality of the engine gas. Whenever the gas supply from the furnaces on which the gas-cleaning plant is directly drawing happens to cease, in other words during checks or repairs, or if one or several of these furnaces are in trouble, disturbances are created in the regular flow and therefore in the quality of the gas, so that momentarily, or for longer periods, richer or leaner gas from other furnaces near the gas-cleaning plant intake is delivered to the gas engines. That such disturbances exist was very strikingly

proved in many instances. The gas engines, which had been operating smoothly, apparently receiving very uniform gas, would suddenly begin to backfire, or to have premature explosions and become very unsteady. These abnormal occurrences would be repeated at short intervals, although possibly lasting only a few minutes. The operating engineers soon discovered the cause of their troubles, and reported in their language that "a bad batch of gas" had caused the backfiring or the premature explosions and the "swinging" on the line. Such pronounced "waves" in the quality of the gas will often affect first the engine nearest to the gas holder, the trouble gradually extending to the engines down the line, and will stop first at the engine where the trouble started, gradually lessening on the rest of the engines, or else all engines will be affected simultaneously.

28 These interesting phenomena, and their bad effect on the parallel operation of the gas engines, prompted investigations which almost invariably located the causes for the sudden increase in hydrogen and methane. It was found that slipping of the furnaces was very frequently followed by backfires and premature explosions; and whether or not part of the raw wet stock in the furnaces reaches the incandescent zone, due to the upheaval of the material inside the furnace during slipping, thereby causing the formation of excessive amounts of hydrogen, remains an open question. Violent premature explosions and backfiring could in very many cases also be traced back to leaking tuyeres or hot blast valves, and these were so pronounced at times that the gas engines often fairly served as an indicator of such leaks.

29 The following gas analyses made on February 10, 1909, at the power house, give a good illustration of the suddenness of these changes:

GAS ANALYSES AT POWER STATION LABORATORY

ENGINE GAS

Time	CO_2	CO	H	CH_4	B.t.u. by analysis
11.00 a.m.....	14.9	24.5	3.5	0.2	90.9
12.30 p.m.....	13.8	24.7	4.3	0.3	94.6
3.30 p.m.....	14.5	25.0	6.5	0.1	90.9
4.10 p.m.....	14.2	24.8	4.5	0.2	94.7

The increase in hydrogen of almost 100 per cent between the first and third analyses is noteworthy. The effect on the engines was the occurrence of violent premature explosions around 3 o'clock of that

firing happened simultaneously on three engines in opera-
ıust 17, 1908, and was caused by fluctuations in the compo-
s. The daily chemical report for the 24 hours ending 6.00
st 18, contains the following record:

CHEMICAL ANALYSIS, AUGUST 18

	CO_2	CO	H	CH_4	B.t.u. by analysis
..	10.9	27.6	3.6	0.2	101.2
..	6.4	33.2	4.4	0.2	121.6
..	8.4	30.2	4.4	0.2	111.9
..	8.0	30.2	3.5	0.2	109.4

simultaneous calorimeter determinations gave the fol-
t values:

CHANGE IN HEAT VALUE BY CALORIMETER

ıe	B.t.u.	Time	B.t.u.
.....	101.3	1.00 p.m.....	115.2
.....	102.7	1.30 p.m.....	118.3
.....	103.9	2.00 p.m.....	110.7
.....	105.0	2.30 p.m.....	110.3
.....	105.9	3.00 p.m.....	112.0
.....	106.4	3.30 p.m.....	108.5
.....	108.6	4.00 p.m.....	109.3
.....	109.5	4.30 p.m.....	110.4

'alue of the gas increased almost 20 B.t.u., or about 20
less than three hours, due to heavy coke blanks charged at
:e No. 1 which was in trouble. In this particular instance
udden increase in carbon monoxid which caused the back-
vas not always possible, however, to prove by analysis or
:ter test that a sudden change in the heat value of the gas
ıtary increase in hydrogen had taken place when prema-
ccurred; nevertheless, following the example of the Lacka-
l Company, the pressure of the cooling water for tuyeres
ıst valves was reduced to a little below the normal blast
all furnaces. Thus water-leaks into the furnaces were very
ıtopped and one principal cause for premature explosions
ıes was removed.

kind of iron produced by the different furnaces at different
, considerable effect upon the quality of the gas. Thus in
1909 the average heat value of the gas at the power station
3.t.u. per cu. ft., because during this month blast furnace

No. 1 was making ferrosilicon with a coke consumption of ov lb. per ton of product. The average analysis of the gas of this is given in Table 7, Appendix 2, and the composition of the gas for September is given in Par. 26 of the paper. The rich which the engines ever received occurred September 17, 19 average of the analyses for the day being as follows:

CO_2	CO	H	CH_4	$\frac{CO}{CO_2}$	by
4.7	34.9	3.2	0.16	7.92	

The average corresponding B.t.u. values determined by cal were 122.5 per cu. ft. The influence of this rich gas on the op of the engines is shown in the daily record of engine ope Three engines were running and were backfiring and

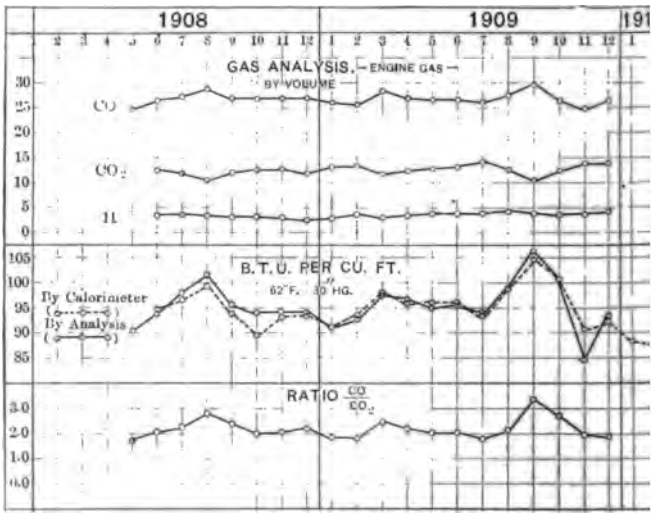


FIG. 4 GAS ANALYSIS AND HEAT VALUE OF BLAST FURNACE GAS (I AVERAGES)

premature explosions all day long. On the following day t ating engineer reported that the gas made a quick change ab a.m. to very poor quality, causing all engines to misfire and about one-half of their load, and the richness of mixture ha changed on all engines to obtain proper ignition. About 2.00 gas became suddenly very rich and the engines again backfire ily, necessitating additional changes in the mixture. The lea

on which these engines were operated during the year 1909 occurred in November, the average composition for the month being as follows:

CO_2	CO	H	CH_4	$\frac{CO}{CO_2}$	B.t.u.
13.8	24.7	3.59	0.19	1.79	86.7

The lowest daily average heat value occurred on November 16, with gas of the following analysis:

CO	CO_2	H	CH_4	$\frac{CO}{CO_2}$	B.t.u. by analysis
15.8	22.1	3.3	0.3	1.39	83.1

The gas was so poor that day that it was impossible to keep it burning in the calorimeter. The lowest heat value ever recorded is 79.5 B.t.u. per cu. ft. on November 17, the gas analysis at 12 o'clock noon giving the following results:

CO_2	CO	H	CH_4	$\frac{CO}{CO_2}$	B.t.u. by analysis
17.1	21.6	3.1	0.1	1.26	79.5

The effect of such very poor gas on the engines is quite noticeable; the full output of the generators could not be maintained, although the proportion of air and gas was changed to meet the new conditions.

32 In Appendix 2, Table 9, are given the average composition of the blast furnace gas for each month, averages for the first and second halves, and the average for the whole year of 1909; further, the heat value of the gas determined by calorimeter. In Fig. 4 herewith these values are plotted for each month beginning with June 1908 when the systematic records commenced. The discrepancies in the heat values as computed, and as determined by Junkers' calorimeter, are explained by the fact that analyses are made about every three hours, while calorimeter readings are taken almost continuously during the day. The number of observations is therefore much greater for the latter than for the former. For all calculations the heat values determined by calorimeter are used exclusively. The methods of gas sampling and analysis used as described by Mr. L. A. Touzalin are as follows:

Daily samples of blast furnace gas are taken at each individual furnace, all samples being accumulative and representing a fair average of the gas production extending over a period of 24 hours. The sample is taken between downcomer standpipe and dust catcher (as shown in Fig. 5) and conducted by means of a 2½-in. or 2-in. pipe, first to a miniature dust catcher and then to two washing bottles connected in series by means of a 2-in. pipe. From the second bottle

the gas passes to a sampling tank of 5 cu. ft. capacity, made of galvan and of regular gas-holder construction. All water used in the washin and in the sampling tank is first saturated with blast furnace gas. T dust catcher consists of an 18-in. length of 6-in. iron pipe capped at and suspended in a vertical position. By removing the cap at the bot the accumulated dust may be cleaned out as often as necessary. T placed at the lower end permits a small stream of gas to flow con through the sampling pipe into the small dust catcher and escape int A great deal of dust escapes with this gas, and besides preventing cc clogging, this valve allows any condensed water to drain off. The s attached to the rubber tube between the washing bottles affords me adjusting the rate of flow that the tank is almost filled in 24 hours. A of each period a sample of the accumulated gas in the tank is withdra glass gas holder of 250 cu. cm. capacity, while the remaining gas in th allowed to escape into the air. The bell of the tank thus drops down and the gas is again started for the next 24-hour sample. The 250 cu. cr of the gas in the gas holder is taken to the laboratory for analysis. At station, where a special gas laboratory, fully equipped, is installed, ga are taken directly from the gas main between gas holder and engi analyses are made several times during the day and as often as ne any unusual occurrences at the engines indicate a change in gas qua

33 Daily gas analyses and heat values as well as results of moisture determination, together with additional chemical tion, are recorded on daily report sheets (Fig. 6).

DESCRIPTION OF GAS-CLEANING PLANT

34 When the installation of blast furnace gas engines was on in 1906, very little information and experience on the in matter of gas cleaning were available in this country. Som ments had previously been made on a small scale at the pla discussion with different designs of wet scrubbers and baffle the idea being prevalent at that time that gas could be sufficiently for engine purposes by so-called "static" that is, by passing it through towers filled with baffle plat checker work of wood or iron, and sprayed with water in finely form. The results of these experiments were discouraging, have been expected, and the installation of Theisen gas wa refining the gas was eventually decided upon.

35 The blast furnace gas for the gas engines is cleane distinct stages. It is first subjected to a preliminary dry scrubbing in the so-called primary or preliminary cleanin and subsequently undergoes a secondary cleaning or refi Theisen washers in the secondary washing plant. Fig. 3 sh

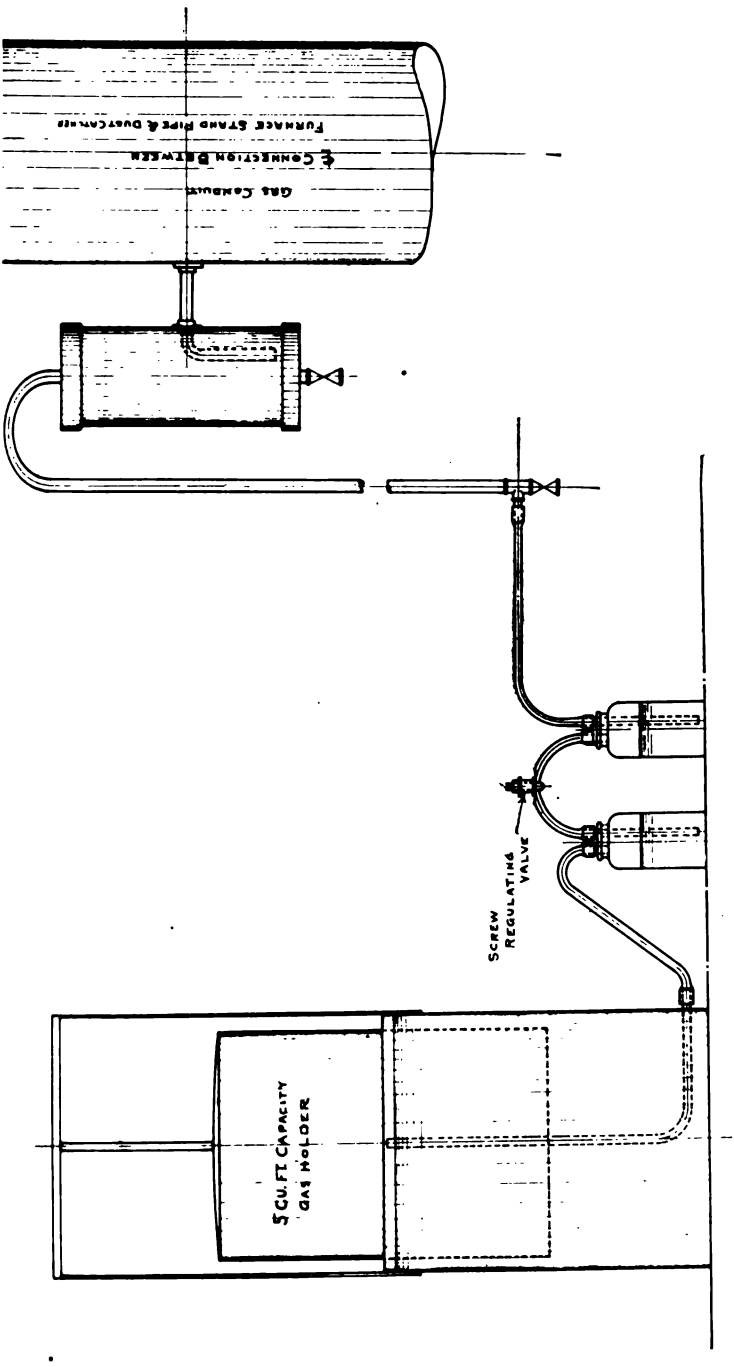


FIG. 5 APPARATUS FOR CONTINUOUS GAS SAMPLING

DAILY CHEMICAL REPORT For 24 Hours Ending 6 A.M. Tuesday, Sept. 21st [illegible]

TIME	BLAST FURNACE GAS Samples taken at Gas power station Laboratory — CHEMICAL ANALYSIS % By Volume: CO 2	CO	H 2	CH 4	CO_2/CO	CO/CO 2	B.T.U. Per Cubic Foot: By Analysis	By Junkers' Calorimeter
9:00 A.M.	8.1	31.1	3.6	.2	.260	3.84	112.6	112.0
9:30								111.9
10:00								111.0
10:30								121.2
11:00	8.2	32.2	3.7	.2	.255	3.92	116.5	119.9
11:30								116.2
12:00 NOON	8.2	32.2	3.0	.1	.255	3.92	113.6	114.0
12:30 P.M.								113.1
1:00								112.7
1:30								111.1
2:00								110.7
2:30								113.1
3:00								112.5
3:30								112.7
4:00	8.7	31.0	5.0	.1	.280	3.56	115.2	114.3
4:30								114.7
AVERAGE	8.3	31.6	3.8	.2	.262	3.81	114.5	113.8

		DAY TURN	NIGHT TURN	AVERAGE
Weather		Fair	Clear	–
Barometer		29.40″	29.31″	29.35″
Direction of Wind		Southwest		
Test Started		8:40 A.M.	5:00 P.M.	–
Test Ended		4:40 P.M.	8:00 A.M.	–
Number of cubic feet of gas passed through filter	Before Scrubbers	39.10	54.20	46.65
	After Scrubbers	59.22	100.63	79.92
	After Theisens	–	–	–
	A.C. Station Gas	88.36	148.37	118.37
	Blowing Eng. Gas	–	–	–
Moisture Grains per cu. foot	Before Scrubbers	–	–	–
	After Scrubbers	14.719	–	–
	After Theisens	–	–	–
	A.C. Station Gas	8.984	–	–
	Blowing Eng. Gas	–	–	–
	In Air	6.49	6.16	6.32
Flue Dust Grains per cu. foot	Before Scrubbers	3.8830	4.0812	3.9821
	After Scrubbers	.8147	.6884	.7516
	After Theisens	–	–	–
	In A.C. Engine Gas	.0065	.0052	.0068
	In Blowing Eng. Gas	–	–	–
% Dust Removed-Scrubbers		79.0	83.1	81.0
% Dust Removed-Theisens		98.9	99.2	99.0

Note-All figures given on this report are reduced to standard conditions i.e.
Temperature 62°F, Barometer 30″ Mercury
The heat value Constants are;
CO---324.45 B.T.U. PER CUBIC FOOT
H2---274.78 " " " "
CH4--915.08 " " " "
Metric Conversion Factor
1 Gram-15.43 Grains
MacFarland's tables of Reduction
Factors are used for all calculations within their scope.

OBSERVATIONS-
Furnace 1 on Ferrosilicon.
" 2 Basic iron.
" 3 " "
" 4 " "
" 5 Bessemer iron.
" 6 " "
3 Gas engines in operation.

Wm. Brady CHIEF CHEMIST
Peterson.

FIG. 6 FORM FOR DAILY CHEMICAL REPORT

FIG. 7 GENERAL VIEW OF GAS-CLEANING PLANT, 1908

grammatically the general arrangement of the complete cleaning plant as it existed in 1908, while Fig. 7 gives a photographic view. When the gas-cleaning plant was designed in 1906, the raw gas was not cleaned except by the usual small dry dust catchers at the end of the downcomers of each furnace, and it was decided to install two special dry dust catchers of large capacity to remove the bulk of the heavy dust.

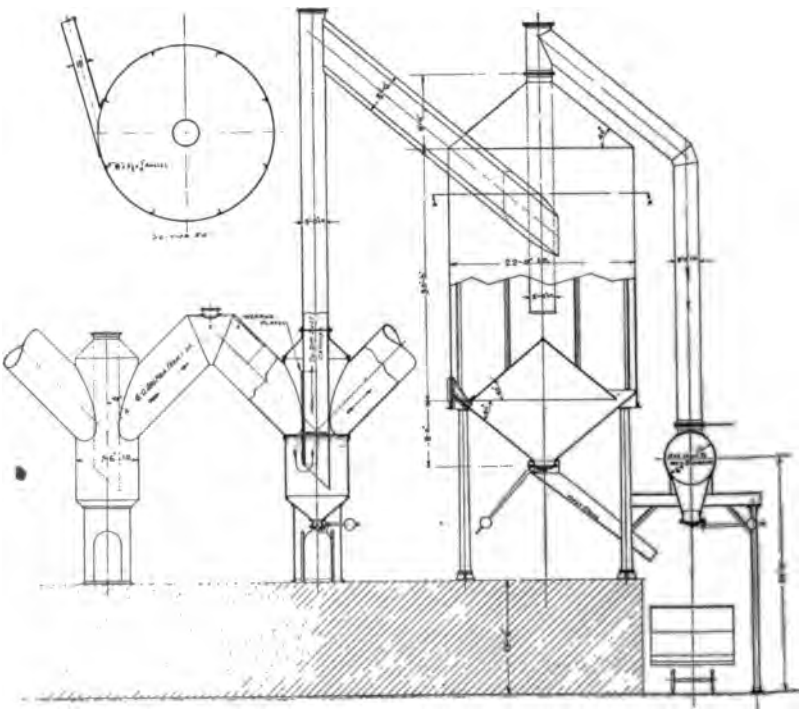


FIG. 8 DRY DUST CATCHER

PRELIMINARY GAS-CLEANING PLANT

36 The raw gas on leaving the overhead gas flue first passes a water seal serving to shut off the gas power plant from the general system in case of necessity, and enters an unlined self-cleaning zigzag gas flue 6 ft. in diameter. Fig. 8 shows the plan in detail, and Fig. 9 a photograph of the zigzag flue and the dry dust catchers. It was originally intended that the capacity of the preliminary cleaning plant should be subsequently increased by the addition of enough dry and wet scrubbers to clean the total quantity of gas produced by all six furnaces, for

ler boilers and in hot blast stoves, and provision for these addi-
as made when designing the cleaning plant. By means of water
a the "dust legs" supporting the zigzag flue, and spectacle
at the points of discharge of the dry-dust catchers into the
ting main," each dust catcher may be shut off during the
on of the plant, in case of repairs or cleaning. As shown in the
tions these water seals were designed on the principle of the
ord valve, and by cutting off the ends of the inside pipes at an
it was intended to provide means of regulating the amount of
ssing through each dry dust catcher by filling the seal with
o a certain height, which was regulated by telescopic overflow.

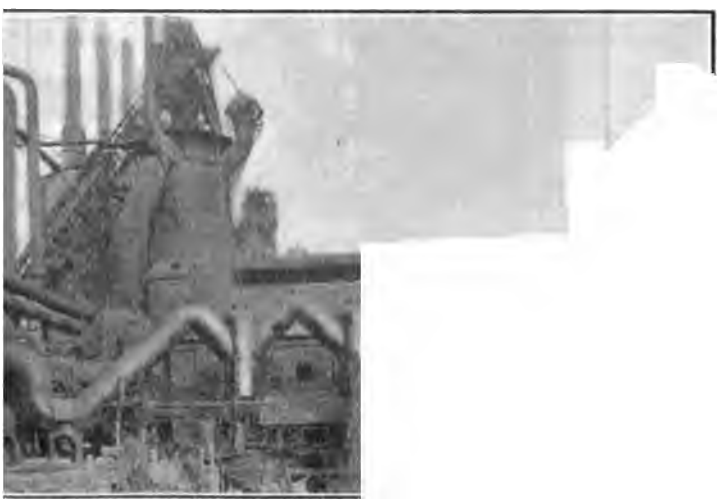


FIG. 9 ZIGZAG MAIN AND DRY DUST CATCHER

Neither zigzag main nor dry dust catchers were lined with fire
as had heretofore been the practice with all gas pipes conveying
s of high temperature, as it was desired to take advantage of the
on of temperature by radiation of heat through the unlined
ork. The results given elsewhere prove that the desired ob-
as very satisfactorily accomplished. At all points of sudden
in direction of the flow of gas, "wearing" plates were provided,
ssive wear of the plate work, from the impinging of the dust-
gas, was expected. These plates can be removed and replaced
ones, through manholes arranged for this purpose. The dust

legs, as well as the dry dust catchers, were raised above the yar high enough to permit the disposition by gravity of the accun flue dust into railroad cars by means of bell valves and dust s

38 The dry dust catchers, two in number and operating in lel, were 22 ft. in diameter by 31 ft. high with 9-ft. cones at ea The choice of the diameter of the dry dust catchers, as well as

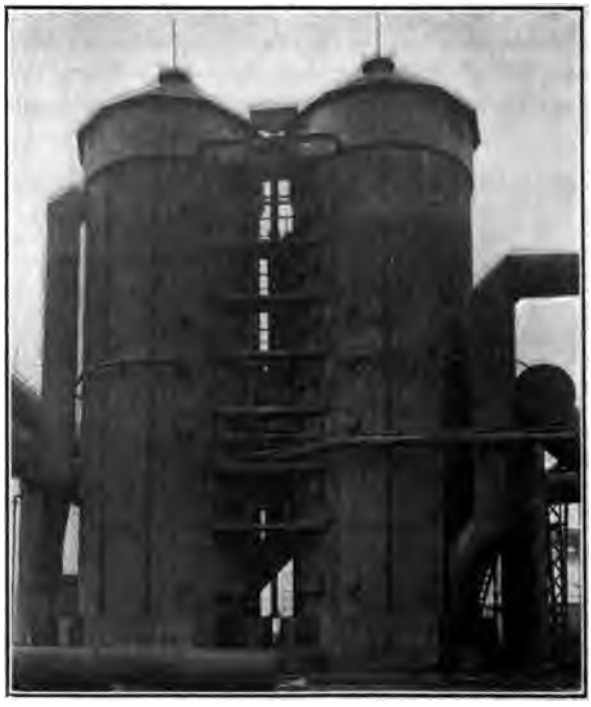


FIG. 10 WET SCRUBBERS

wet scrubbers, was accidental, as it happened that some old 22 blast stove shells were available at the time. The dry dust c were given tangential gas inlets, assuming that by this arrang and by inclining the flattened gas-inlet pipe, the gas would be to travel in long spirals from top to bottom, thus lengthening tl of the gas; and angle irons were placed vertically on the inside shell to provide for increased friction while the gas was tr through the dust catchers at the slow rate of 1.5 ft. per sec

bottom cone was separated from the cylindrical part of the dust catcher by an inverted cone arranged umbrella-wise to prevent the dust accumulated in the bottom cone from being stirred up by disturbances caused by furnace slipping and re-entering the gas. The gas left the dry dust catchers near the apex of the umbrella, passing through a self-cleaning pipe into the collecting main and hence to the wet scrubbers. Explosion doors were arranged for on the dry dust catchers, but were eventually bolted down as unnecessary.

39 From the 78-in. collecting main, the dry-cleaned gas passes to the wet scrubber, shown in Figs. 10, 11*a*, 11*b* and 11*c*, through self-cleaning pipe lines. The piping arrangement permits the operation of the original two wet scrubbers in series, or in parallel, by turning a num-

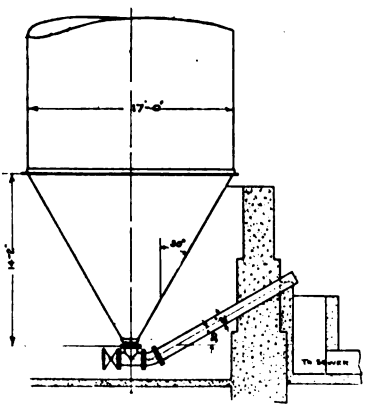


FIG. 11*a* DETAIL OF SCRUBBERS NOS. 1 AND 2

ber of spectacle valves, and water seals allow the shutting-off of either wet scrubber for cleaning, without interfering with the operation of the power plant. From the start the two wet scrubbers were operated in series, the total quantity of gas consumed by the engines passing first one and then the other. The gas enters each wet scrubber at the bottom of the shell, which is 22 ft. in diameter and 55 ft. in height. The inside is divided horizontally into six compartments, each containing eight rows of slats made of clear No. 1 white pine dressed all over. Each system of slats is supported independently by I-beams and angle irons riveted to the shell. The slats are 5 in. high and $\frac{7}{8}$ in. thick, by about 5 ft. 6 in. long, and ten slats on an average are nailed to distance pieces, forming hurdles about 5 ft. 6 in. long, and 3 ft. 7 in. wide, a size and weight which permit of easy handling. An

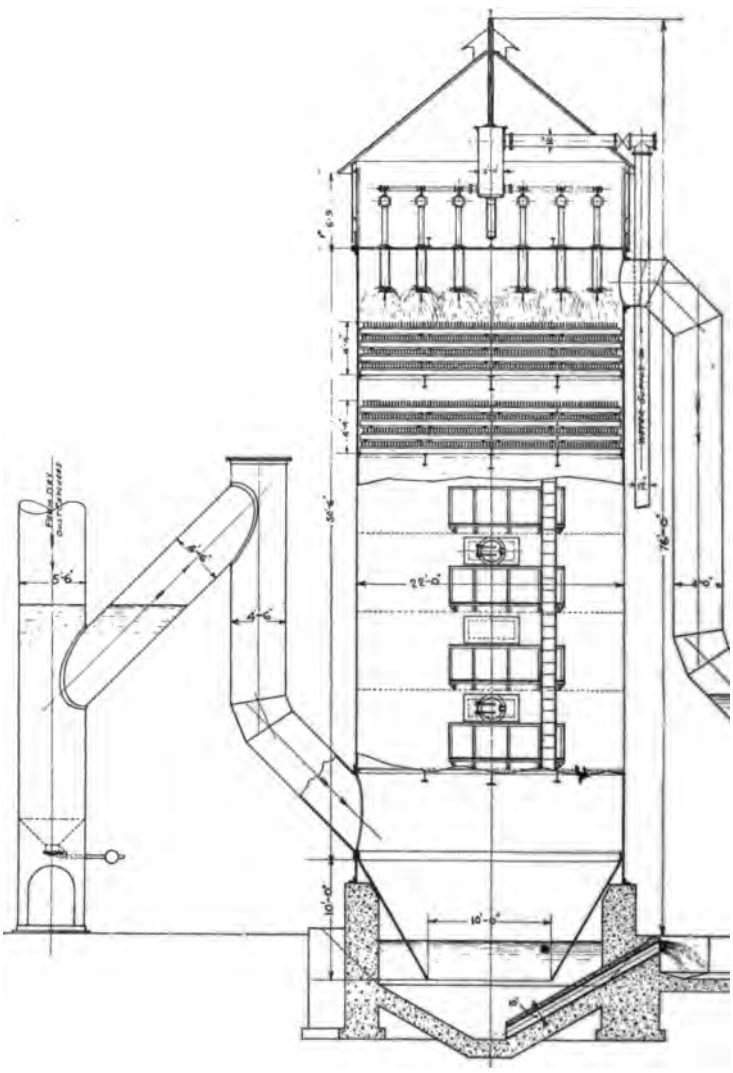


FIG. 11b SECTION OF SCRUBBERS NOS. 3 AND 4

interior view of the scrubbers with the hurdle arrangemer
in Fig. 12.

40 Profiting by the experience gained elsewhere with we
of the same kind, flue dust bridging over between slats and c
hurdles, it was decided to space the slats in the followir

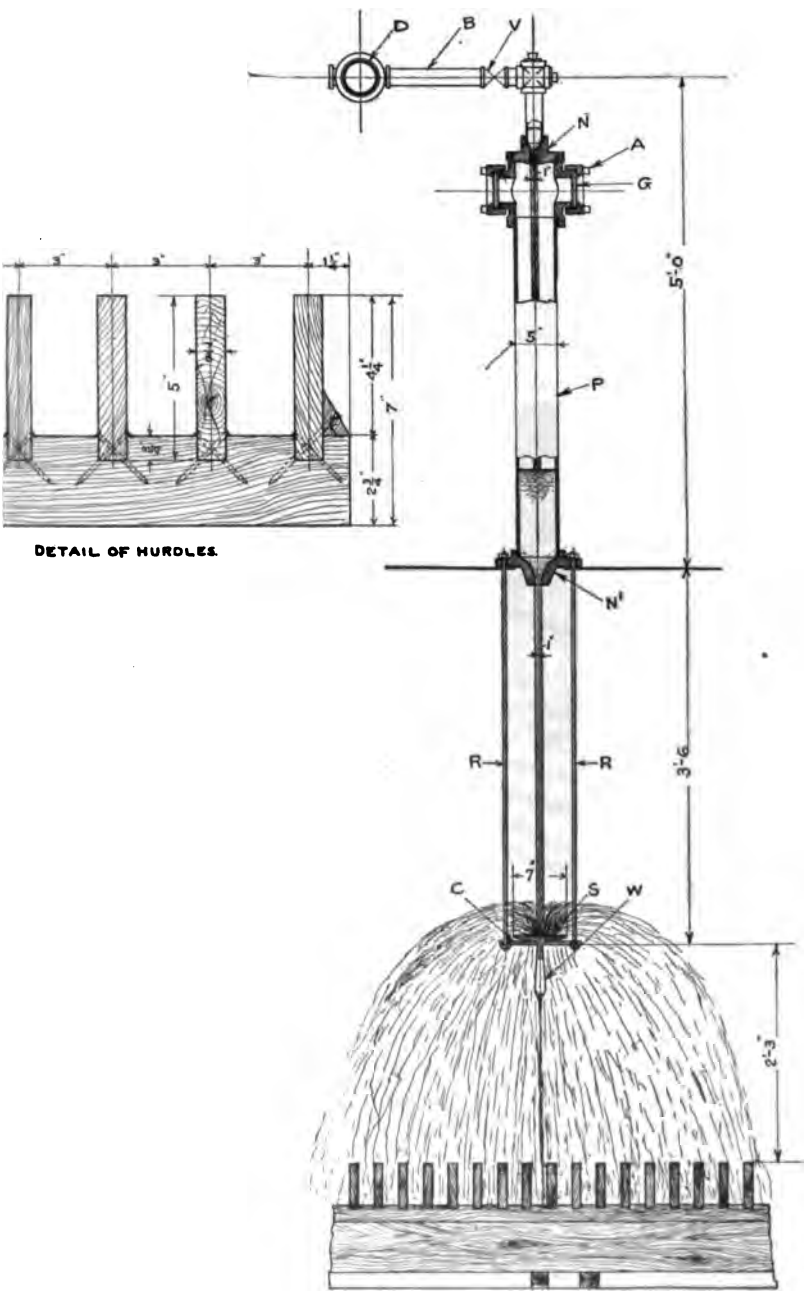


FIG. 11c DETAIL OF SPRINKLERS AND HURDLES

In the three lower compartments of scrubber No. 1, which receives dry-cleaned gas containing a large amount of coarse flue dust, the average distance of the slats was made 9 in., while in the three upper compartments the slats have 6-in. spacing. In the three lower compartments of scrubber No. 2, receiving gas already washed in the first scrubber, the slats were spaced with 4½-in. centers, while the corresponding distance is 3 in. in the three upper compartments of the second scrubber. All hurdles were placed in the different rows and compartments in such a way that the slats of each upper row straddle the slats of the row immediately below, thus obtaining a continuous

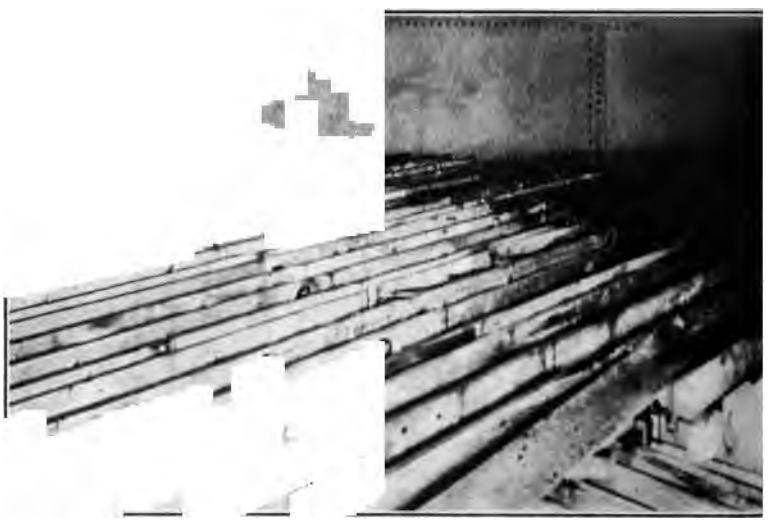


FIG. 12 INTERIOR VIEW OF SCRUBBERS SHOWING HURDLES

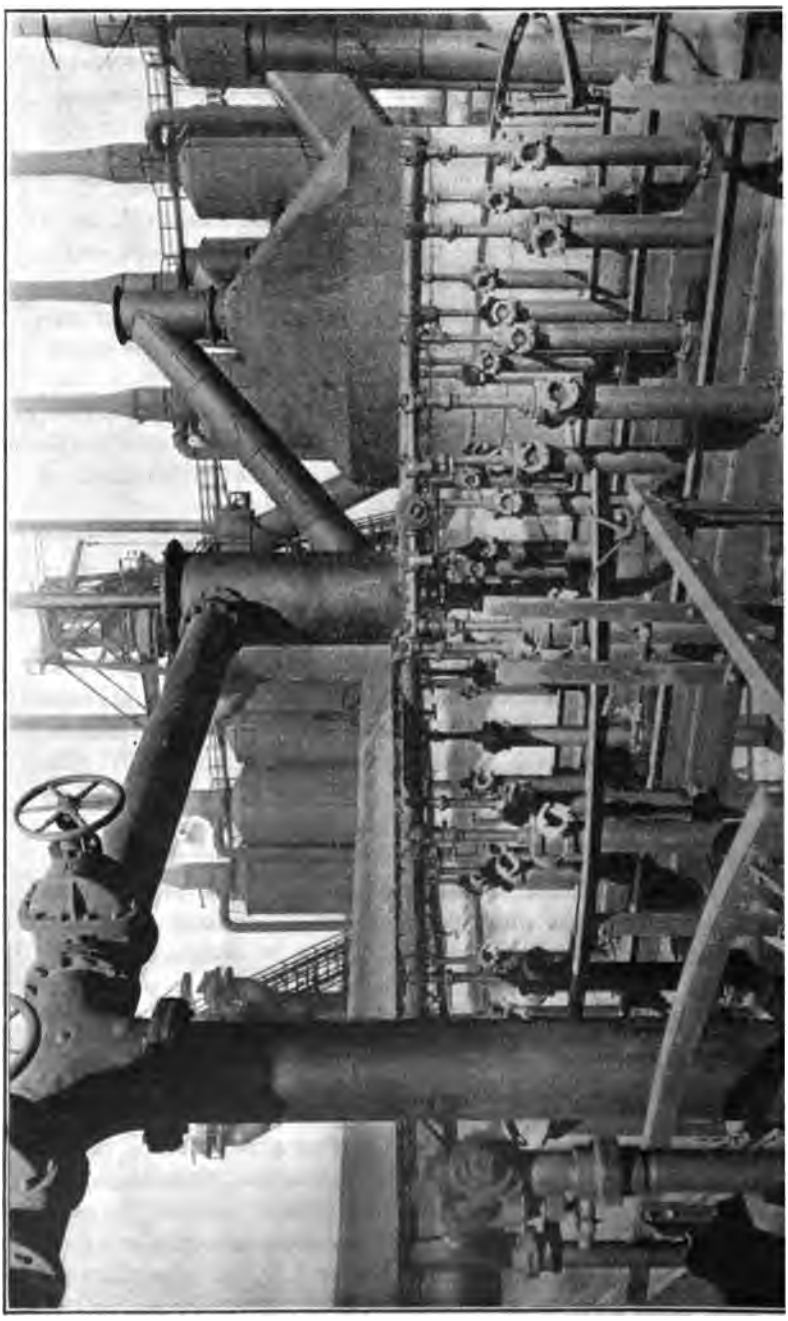
checker arrangement without any channels. A space of about two feet was left between each two hurdle sets, making each compartment accessible for cleaning or changing hurdles without removing the whole filling, and manholes and platforms were provided to facilitate this work.

41 The top of the wet scrubbers is formed by $\frac{1}{16}$-in. flat covers supported by 8-in. I-beams. Each cover plate supports 36 sprinklers, shown in Fig. 13 and in detail in Fig. 11*c*, distributed over the entire section. Each sprinkler consists of two nozzles *N* and *N'*, and cast-iron spray plate *S* with slightly curved surface and weight *W*

to insure horizontal position. The spray plate is inserted in the center hole of the crosspiece C, which is supported by two rods R fastened to the top cover plate. The upper nozzle of 1-in. diameter is mounted on one branch of a cast-iron cross, while the opposite branch is connected by a 5-in. wrought-iron pipe P about three feet in length, to the lower nozzle N' of equal size. The other two branches of each cross are closed by caps A, containing plate glass discs G, $\frac{1}{4}$ in. thick and 4 in. in diameter. The open water tank located above the wet scrubber supplies the washing water under a small but constant head, through distributing pipes D and branch connections B to the sprinklers, the amount of water being regulated by valves V. The operation of these sprinklers is obvious. A stream of water falls in each sprinkler through a distance of about eight feet, breaking up into an exceedingly fine mist by impinging on the spray plates, and as the sprays of the 36 sprinklers overlap each other, the distribution of water is perfect.

All these sprinklers were tested before the wet scrubbers were put in operation, and one minute after turning on the water there was not a dry spot on the inside of the scrubbers. Originally these sprinklers were without the nozzle N'. The action was the same as far as the distribution and the atomization of the water was concerned, but with the serious drawback that the dirty gas could reach the upper part of the sprinklers and deposit dirt on the sight glasses, which soon became useless. By the insertion of nozzle N' this trouble was successfully overcome, as the water flowing through this nozzle completely seals the upper part of the sprinklers so that the glasses can be removed during operation without danger from escaping gas. The great advantages of this type of sprinkler are that a clogging of the water passages can never occur, and that uniform distribution of the water can always be obtained. Their operation has been exceedingly satisfactory. All water piping on top of the wet scrubbers is housed-in for protection against frost.

43 The lower part of the wet scrubbers dips with a conical extension into a water seal provided in the concrete foundation. The muddy water is carried off through an overflow pipe reaching to the bottom of the seal, thus keeping the water in constant circulation and thereby effectively preventing any accumulation of mud in the seal. It was found advantageous, however, to introduce into this overflow passage and reaching to the bottom of the seal, a 1-in. pipe through which water under pressure is constantly discharged, stirring up the



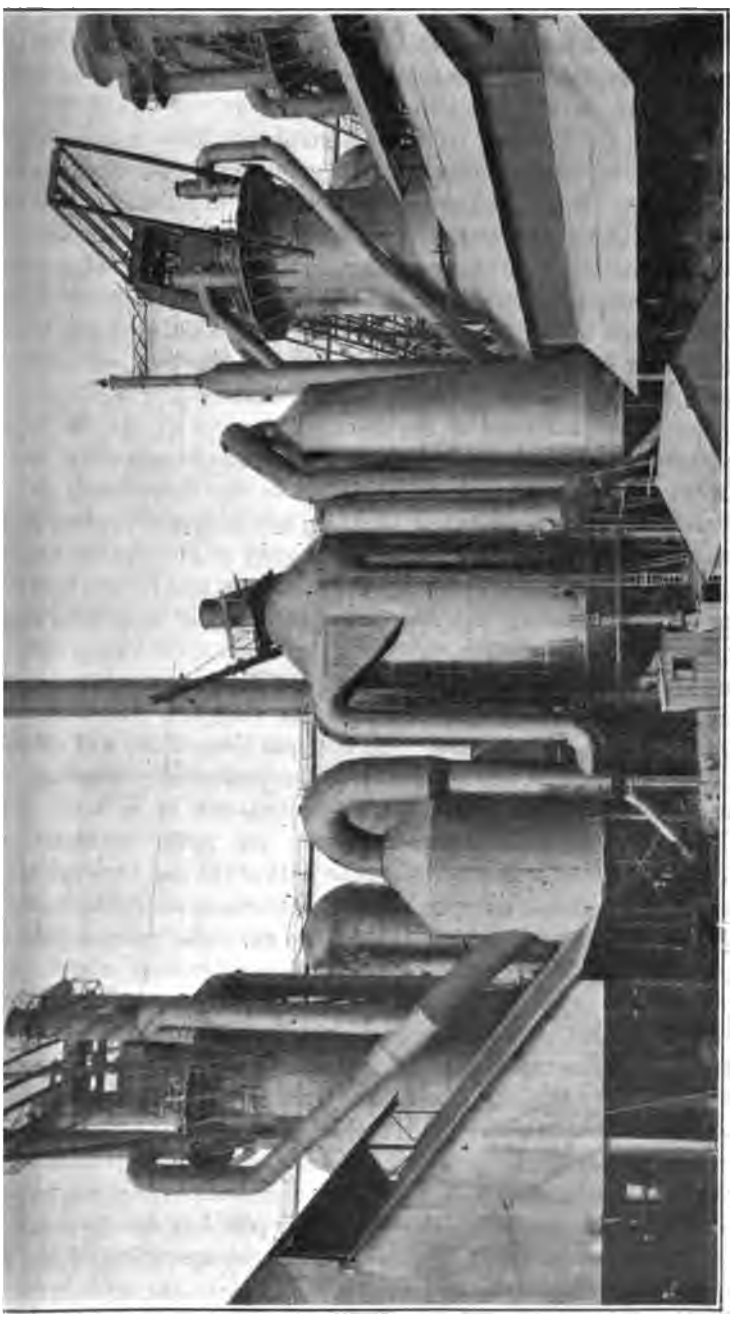


FIG. 14 DRY DUST CATCHER SYSTEM AT FURNACES 5 AND 6

sediment and keeping the water in motion. On the two new wet
bers recently installed this type of water seal was abandoned in
of the simple arrangement shown in Fig. 11*b*.

44 The waste water from these scrubbers flows into a large
tling tank, which was installed to prevent a possible clogging o
main sewer. Both compartments of the settling tank, which wa
operation about two years, have since been completely filled w
mud, but as the dust in suspension does not prove to be trouble
in the sewers, little attention is being paid to their regular clean

45 When in the early part of 1909 four additional gas blow
engines for blast furnaces No. 1 to 4 were purchased, an increa
the capacity of the gas-cleaning plant was necessary, and since in
meantime the question of dry cleaning the raw gas at the furna
had been solved, it was decided to change the two original dry d
catchers into wet scrubbers. As soon as the voluminous dry d
catcher system at the furnaces (Fig. 14) was in operation, its effect
noticed in the materially reduced efficiency of the dry dust catch
in the preliminary gas-cleaning plant. These had formerly remo
a great deal of heavy, dry flue dust, but suddenly became practic
useless, and only a little dust, now in the form of mud, was ta
out. While the change from dry dust catchers to wet scrubbers
being made, in the second half of 1909, only the two original
scrubbers were in operation. In the near future four wet scrubb
of sufficient capacity to take care of the preliminary washing of
gas required by 40,000 h.p. in gas engines, will be in use. Fig.
shows the general arrangement of the gas power installations
present. Fig. 16 is a diagram of the path of the gas through the
wet scrubbing plant, showing the combinations in which the four scr
bers can be operated. Fig. 7 shows the gas main carrying the cl
gas from the wet scrubbers to the secondary cleaning plant. Att
tion is called to the design of the supports of this pipe line, which
built as so-called dust legs, wherein water and flue dust are deposit
and drawn off occasionally through bell valves. The clean gas ma
while not self-cleaning, is arranged to slope in both directions.
certain intervals circular water pipes with spray arrangements
installed for flushing the clean gas main, and at the points wher
sudden change of direction of the gas occurs sealed holes are provid
through which a thorough cleaning of the pipe line can be made, w
fire hose and high-pressure water, during the operation of the pla

46 After leaving the wet scrubbers, the clean gas, as it is called
in such a condition that it could be used under boilers and in hot bl

FOLDER No. 4

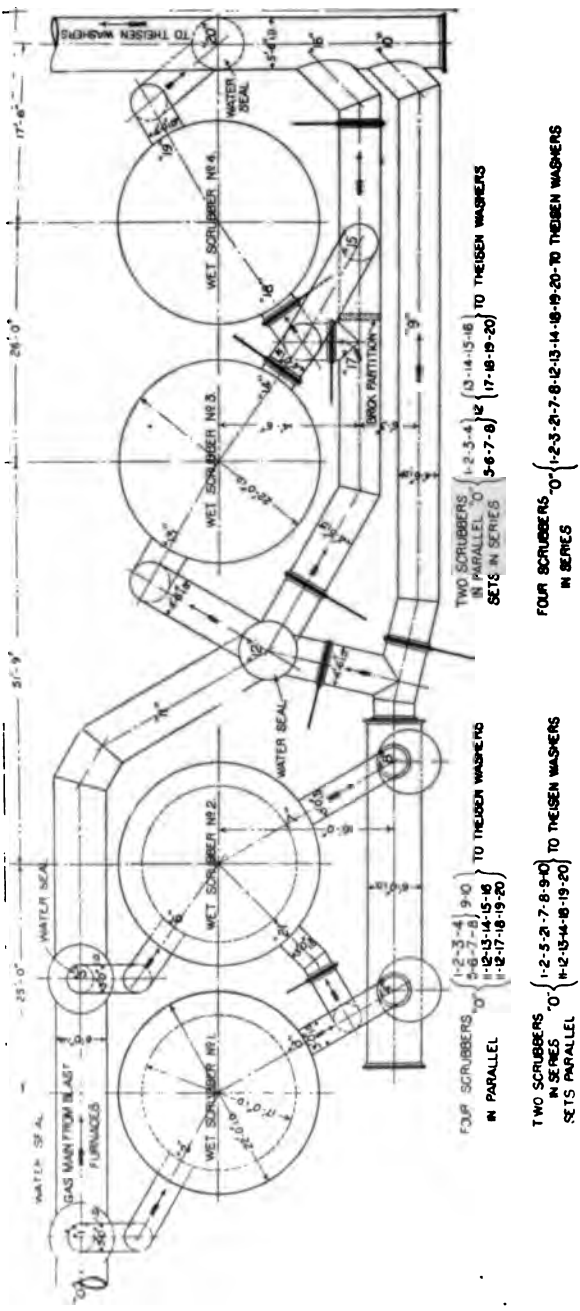


FIG. 16 FLOW OF GAS THROUGH WET SCRUBBERS

stoves, if desired. In 1909 it contained an average of not mor
0.318 grains of dust and not over 5.62 grains of moisture per cubi
Its purity therefore nearly complied with the requirements of
pean blast furnace plants where 0.5 grammes per cu. m. (
grains per cu. ft.) is considered a desirable degree of cleanlin
stove and boiler gas.

IMPORTANCE OF GAS CLEANING

47 Clean gas as delivered by the preliminary washing pl
however, not sufficiently purified for gas engine purposes. 1
very many years ago it was sincerely believed that gas e
could operate on dirty gas, and it required years of costly exper
ing to develop the art of gas purification to its present perfectio
the far-reaching importance of the problem was at last unde
Its magnitude can be better appreciated if the total quantitie
and dust which are handled in such a cleaning plant during a
period of time are considered. The following figures apply to
power plant under discussion for the year 1909.

48 The total number of kilowatt-hours generated by the gas
installation was 50,494,100. The average heat consumpti
kilowatt-hour was 17,234 B.t.u. The average heat value of the
calorimeter was 98.3 B.t.u. per cu. ft. The gas engines consume
fore per kilowatt-hour 175.3 cu. ft. of gas, or in the year 1909
of 8,851,615,730, or nearly 9,000,000,000 cu. ft. This total q
of gas reached the wet scrubbing plant containing on an averag
grains of dust per cubic foot. There were consequently carri
the wet scrubbers during the whole year 1,938,500 lb., or 865 gr
of flue dust. To appreciate fully the meaning of this enormous
should be remembered that to haul such a quantity away, a freig
of twenty gondola cars of 100,000-lb. capacity would be require
average amount of dust in the clean gas for the year was 0.3
per cu. ft.; so that it carried 402,500 lb., or 180 gross tons of fl
into the secondary cleaning plant. The difference of 685 t
taken out by the wet scrubbers and carried off into the settling
Expressed in percentage of the original quantity of dust, the we
bers removed 80 per cent of the impurities. The Theisen gas
further took out from the gas 176.7 tons, leaving only 3.3 ton
fine gas, since the average amount of dust in the latter was
grains per cu. ft. The Theisen washers had therefore an effici
98 per cent, shared by clean gas main, fine gas main and gas

The over-all efficiency of wet scrubbing and secondary cleaning plants was 99.5 per cent, since of the original 865 tons, 861.7 tons was removed from the gas and only 3.3 tons entered the gas engines. Of the latter quantity only a small amount remained in the engine cylinders, since the bulk of the dust is swept into the atmosphere at each exhaust stroke. These figures will give a good idea of what it would mean if gas engines were operated on clean gas, not to speak of dry-cleaned gas, and yet this was attempted in the early history of the blast furnace gas engine.

SECONDARY CLEANING PLANT

49 It is generally recognized that blast furnace gas cannot be cleaned sufficiently for engine purposes without the expenditure of power, and that a satisfactory refining can only be performed in rotary gas washers on the "dynamic" principle, in contradistinction to the preliminary washing for which "static" methods are usually found to be fully adequate. Among the rotary gas washer systems on the market, the Theisen washer is considered well designed mechanically and very efficient. The Theisen washer installation consisted in 1909 of four washers, each of 15,000 cu. ft. per min. capacity. One additional washer has been installed recently on account of the new gas blowing-engines. Fig. 17 is an interior view of the Theisen washer building, and Fig. 18 shows the plan and elevation of this installation. The Theisen washers are arranged in two rows in a fireproof building, with the clean gas main overhead between them, and inlet pipes to the suction end of each washer. The outlet pipes pass through the building to water separators and to a ring main which delivers the gas through a 5 ft. fine gas main about 500 ft. long to the power station gas holder, and through a 4 ft. 6 in. fine gas main about 1000 ft. long to the blowing-engine gas holder.

50 The Theisen washer, shown in sectional view in Fig. 19, consists essentially of a closed drum fitted on its outer surface with longitudinal blades arranged in spirals. This drum, supported by a shaft in two water-cooled ring-oiling bearings, rotates at high speed inside of a stationary casing of conical shape. The inlet end is equipped with suction vanes while on the discharge end an exhaust fan is firmly attached to the drum. The gas is introduced into the annular space between revolving drum and conical casing and discharged by the fan into a water separator. The operation of the washer is as follows:

51 The suction vanes draw the gas from the inlet pipe and deliver it to the longitudinal vanes, which have an inclination to the axis of

the drum so as to oppose the flow of the gas through the
discharge fan at the outlet end of the drum, however, o
tendency and discharges the gas under positive pressure c
of water. The clearance between the outer edge of the
blades and the inner surface of the stationary casing is r
1 in. and the gas passing through this narrow space un
sure imparts to the water introduced at several points i
a movement in long spirals in an opposite direction to i
This flow of water in the form of a film covering the inner
stationary casing, is assisted by the conical shape of the

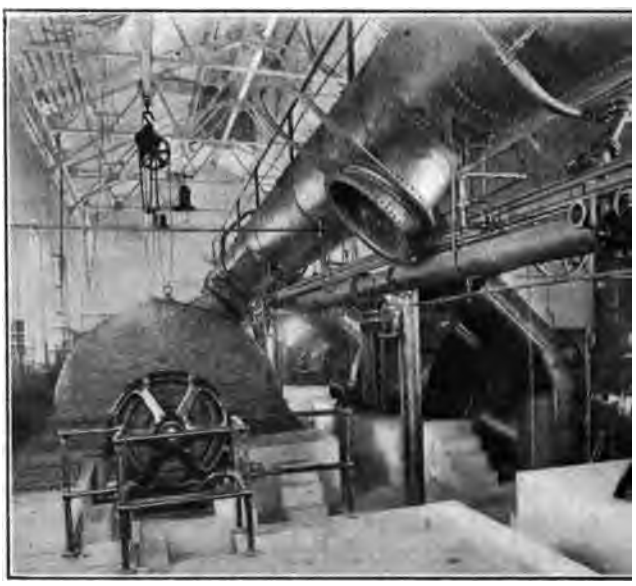
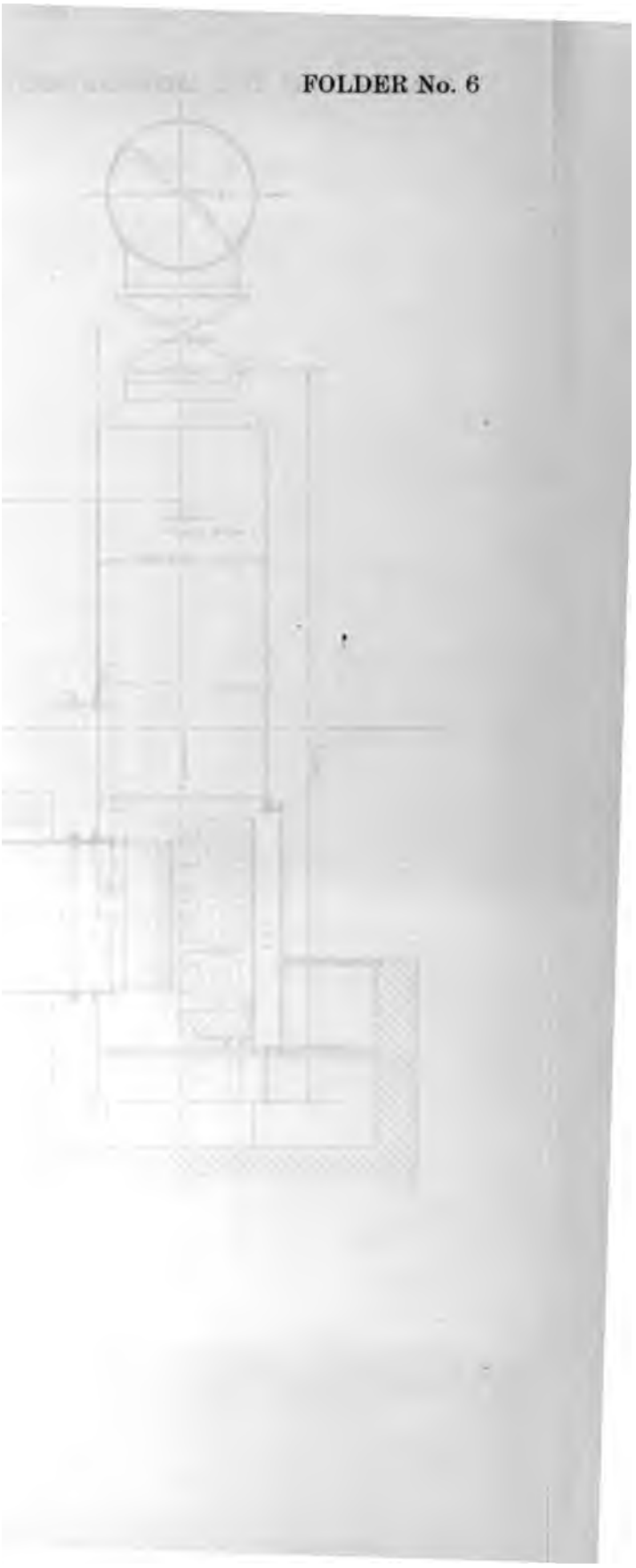


FIG. 17 INTERIOR VIEW OF THEISEN WASHER BUI

ing off towards the gas inlet. The surface of contact be
water is materially increased by wire netting, closely fit
of the casing. By the intimate action of the water on th
particles are thoroughly moistened, and being weighed d
drops, are thrown by centrifugal force into the rotating
to be carried away through a seal into the sewer. The g
washer is charged with more or less moisture in the form
is removed from the gas in the Theisen washer separat
principally of a removable box filled with iron shavings

FOLDER No. 5

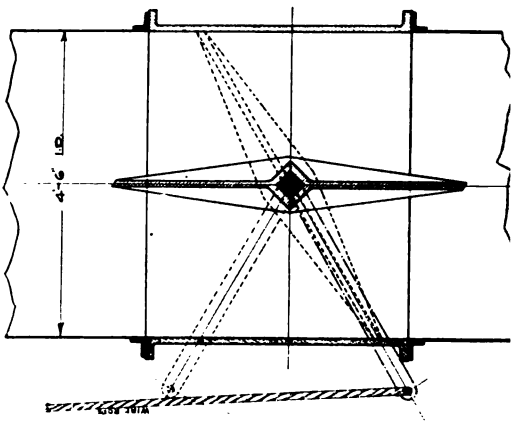
FOLDER No. 6

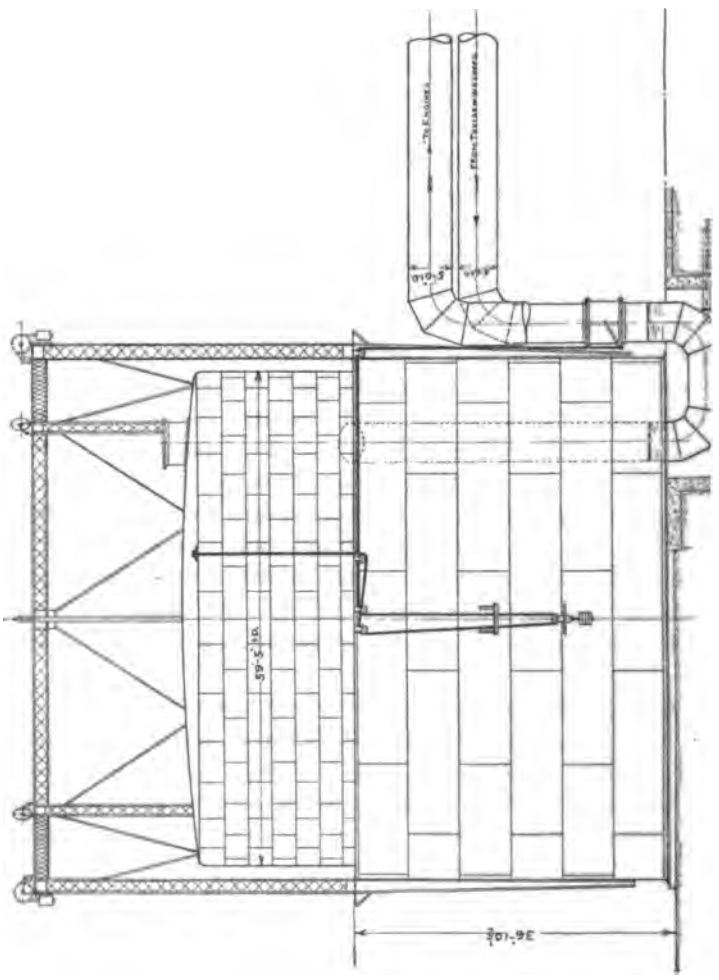


rire netting. The gas striking the iron shavings with great velocity osits its moisture, and as it has to reverse its direction cannot : it up again, but leaves the separator in a comparatively dry con- on. Gate valves serve for regulating the quantity of gas entering different washers, and for shutting off any washer without inter- ng with the operation of the plant.

2 The two gas holders, of 100,000 cu. ft. capacity each, were alled primarily to give a constant pressure of about four inches of er column at the gas engine throttle. Incidentally, however, they 'e as reservoirs and as water separators. Since a gas holder was inally not contemplated for the gas blowing-engine installation, ıdditional water separator, shown in Fig. 20, was provided in the gas main to the gas blowing-engine house, the design of which is ed on a well-known principle. A number of angle irons serve as les, dividing the gas into a number of streams which are forced to ıge their direction several times while passing through the rows of le irons. The latter are placed "straddling" similar to the wooden s in the wet scrubbers. A bell valve at the end of a long pipe serves emove the accumulated water. Each gas holder is of the single- type, with bell 59 ft. 6 in. in diameter by 36 ft. high. Both holders e separate gas inlet and outlet pipes to obtain continuous circula- ı in the holder and prevent the pocketing of stale gas. While in power station holder this idea was carried out to the extent of ing inlet and outlet pipes at opposite ends of one diameter. The wing-engine gas holder has these pipes side by side, but with the t turned a little to impart to the gas a rotating motion. Inlet and let pipes can be used as water seals to shut off the gas holder in case ıecessity. To prevent the possible collapse of the gas holder bell, ase the supply of gas should be interrupted and a vacuum created lerneath the holder bell, a disc valve supported by chains from the der crown is located exactly above the mouth of the outlet pipe. ıen the holder bell descends until it rests on its landing beams, s valve will close the outlet opening, preventing a vacuum under bell.

53 The discharge pressure of the Theisen washers is about 8 in. ;her than the pressure on the suction side, and as the latter is quite riable, the former will also vary within considerable limits. It is course possible to regulate the pressure in the fine gas main by ans of the gate valves arranged in the Theisen outlets; but since ese pressure variations are almost continuous, the gate valves would ve to be adjusted by the operators practically all the time, unless it


4'-6" I.D.


59'-5" I.D.
36'-10"

sired to resort to the complication of electrically operated
nder automatic control of the gas pressure. To simplify this
y regulation a butterfly valve was installed in the inlet pipe
gas holder and operated by the holder bell itself by means of a
le fastened to it and carried over a system of pulleys as shown
1. This device works in the following manner:
When the gas holder is empty, the butterfly valve is wide open
counterweight shown in the left-hand view (Fig. 21) is in
m position. When the bell ascends the counterweight
hout affecting the butterfly valve, until the weight strikes
r bracket which prevents further travel of the weight. The
pulley from which the weight is suspended now becomes
y and the rising holder bell acts on the butterfly valve,
the cable, throttling and finally tightly closing the valve.
t is the same as if the gate valves on the Theisen washer out-
been throttled or closed. The washers continue to operate,
to deliver until the descending gas holder bell again opens
rfly valve. This action is perfectly automatic and it is im-
for more gas to enter the gas holder than is being taken out,
ny number of gas engines can be started or shut down at any
hout the slightest adjustment at the Theisen washers.
ithout this automatic regulator this is what would happen:
ght of the gas container gives a constant pressure of 4 in. of
lumn in the outlet pipe and the Theisen washers deliver a
quantity of gas as long as the gas pressure on the suction side
nt. With a certain number of gas engines in operation, and
emand equal to the gas supply, the gas holder bell will float
in position. If, however, one or several engines are stopped,
emand will decrease and as the gas supply remains constant
ill rise into its top position, determined by the height of the
l in the holder tank. Any further rise will break this seal,
as to escape from underneath the holder bell. This will con-
il more engines are started and the gas demand is again equal
supply, or until the Theisen outlets are sufficiently throttled
the quantity of gas delivered. The disadvantages are ob-
ot only will the breaking of the seal cause large quantities
o be thrown out, but the escaping gas, aside from being un-
ly wasted, will dangerously foul the surrounding atmosphere.
matic butterfly valve, balancing perfectly the gas demand
as supply, eliminates these troubles very effectively.
by-pass line permits the operation of the gas engines directly

if for any reason the holder is out of commission. Each
livers the gas into a large main located on the outside of the
buildings, as shown in Fig. 22. Individual branch pipes l
to each engine, which can be isolated from the gas main by
or water seals, as shown in Fig. 23*a*. The gas pipes lea
engines, as well as all gas mains, are carefully drainec
matic overflows, an important feature.

FIG. 22 EXTERIOR VIEW OF POWER HOUSE: GAS HOLDER AND GA

PERFORMANCE OF THE GAS-CLEANING PLAI

57 The physical qualities of the gas of importance from
point of gas engine operation, are its pressure, temperatu
and cleanliness. These conditions, and particularly t
ascertained and suitably recorded at various stages of tl
process, are valuable indicators of the efficiency of the g
plant; very few blast furnace plants, however, pay sufficien
to their regular routine determination. As a rule tests are l
and results recorded only so long as the gas engine installa
and therefore of all-absorbing interest. Particularly if th
of the plant seems satisfactory, the interest is soon lost an
is left entirely to the care of the operating men, who soon a
authorities on the machinery in their charge. The knov
can be obtained from them is of questionable value, as it is
on good memory only, and gathered in hit-and-miss fa
operative results of a gas power plant should be record
thorough care as is usually afforded the operation of steam
even more, since the gas engine is more susceptible to va
the quality of its fuel.

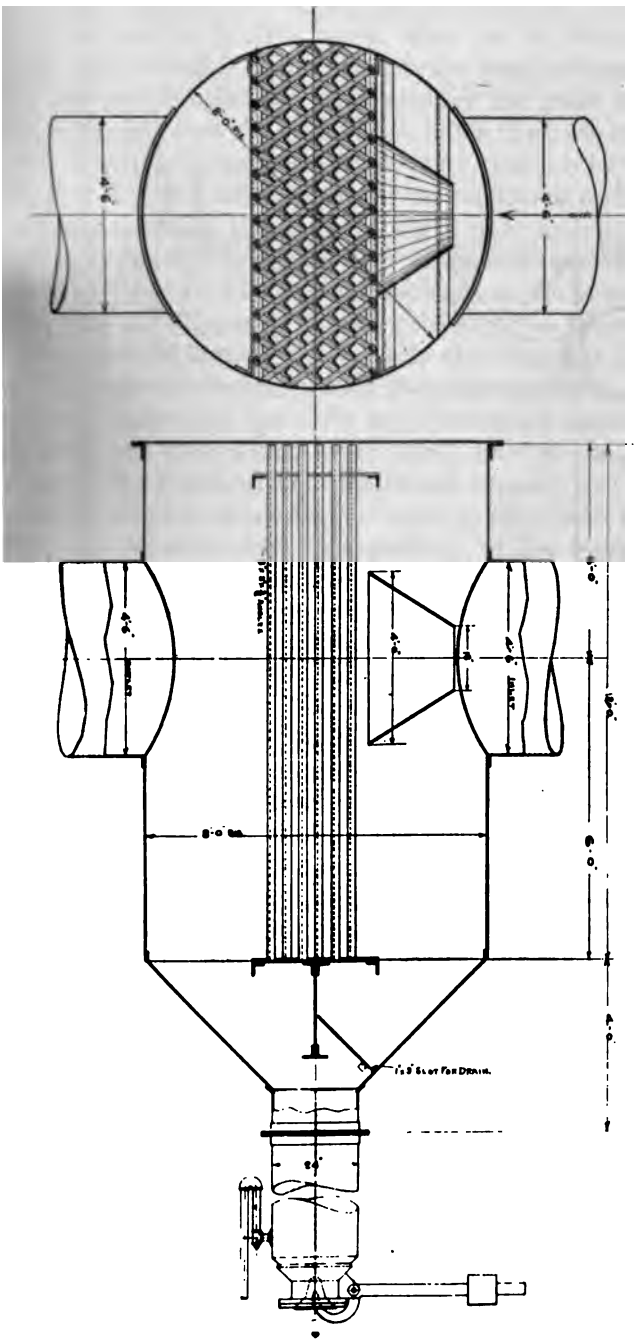
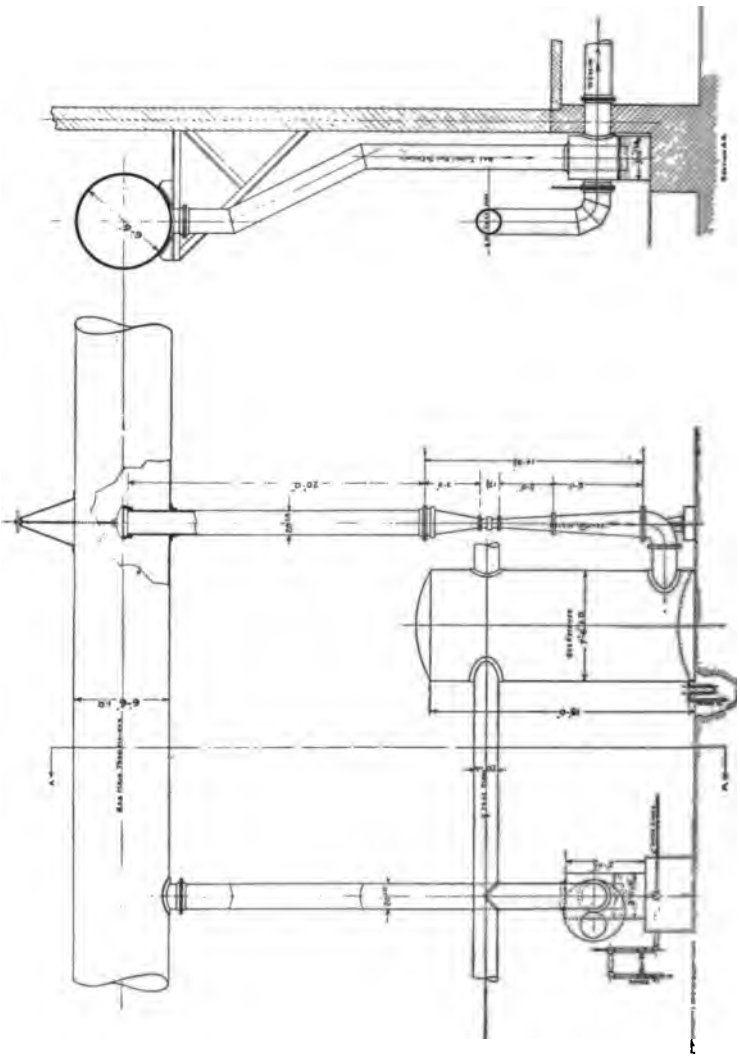


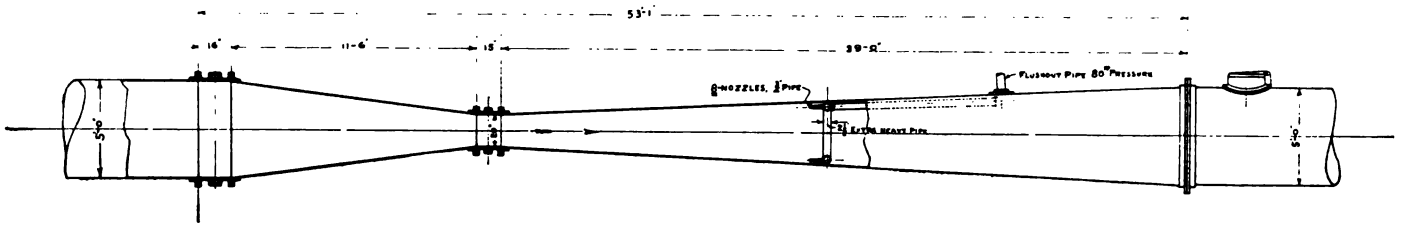
FIG. 20 WATER SEPARATOR



he question is often asked, what can be the advantage of exact records if the recorded results vary comparatively little he year's operation, and whether the game is worth the assuming that the expenditure is far in excess of the benefit

The questioner overlooks, however, that only by keeping such can it be determined whether the conditions really are gener- form; and that this uniformity is in many instances due to the watching and recording of the phenomena involved. Besides ound, in over two years' experience at the plant under dis- , that the expense of "keeping the finger on the pulse" of the er plant is so small and so easily absorbed that it is insignifi- The expense connected with the maintenance of a special gas ory, for instance, has never as yet noticeably increased the cost ron, and the readings every three hours at the gas cleaning re being taken, without additional expense, by the operators lves, who are assisted and checked in their work by recording ients installed wherever expedient. It has been found, too, e installation is being given much more care by the operators, ey are compelled to go over the whole plant on regular beats, r to take the various readings. The general appearance of cleaning plant shows unmistakably the influence of this con- inspection. It is only natural that the operators should lves become interested in their readings and compare the from day to day. They soon make changes and improvements quipment, of their own accord, and will operate the plant at higher standard of efficiency.

Fig. 6 and Fig. 24 show two of the standard record forms, are self-explanatory. The data collected on the various report are tabulated and plotted on charts in the engineering depart- o as to show the daily, monthly and yearly averages. These are very valuable from an operating point of view. The ny of a gas-purifying plant, for instance, is dependent on a r of elements, among which the plant efficiency is not of least ance. It involves the question of total cost per unit of gas, tric light and power consumed in the plant, of operating labor, and material used in repairs, and lubricants in relation to the of cleanliness and the amount of moisture obtained by this expenditure in the same gas unit. The majority of these ele- can be controlled when the variations to which they are sub- by voluntary or involuntary changes are known, but this edge can be acquired only through close and continuous ob- ion.



IG. 23*b* TEST PIPING—60-IN. VENTURI METER

PRESSURES AND TEMPERATURES-DAILY REPORT

FOR 24 HOURS ENDING 6 A.M. Thursday, October 7th, 1909.

TIME		Entering Gas Cleaning Plant T	Entering Gas Cleaning Plant P	GAS TEMPERATURES (°F) PRESSURES ("OF WATER) After Wet Scrubbers 1 T	After Wet Scrubbers 2 T	After Wet Scrubbers 3 T	After Wet Scrubbers 4 T	Before Theisen Washers T	Before Theisen Washers P	After Theisen Washers T	After Theisen Washers P	A. C. Stn. Gas Holder In T	A. C. Stn. Gas Holder Out T	B. Engine Gas Holder In T	B. Engine Gas Holder Out T	WATER TEMPERATURE Pump Suction	Wet Scrubber Waste 1	Wet Scrubber Waste 2	Wet Scrubber Waste 3	Wet Scrubber Waste 4	Waste Theisen Washers	Air Temperature	READING OF AMMETER ON THEISEN WASHER MOTORS AMPERES PER TERMINAL 1	2	3	4	5	6	7	8	WATER CONSUMPTION GAL./MIN. Scrubs.	TS's &c.	No. of Electric Engines in Operation	No. of Blowing Engines in Operation
DAY TURN	8 A.M.	218	17.0	—	—	77	64	68	16	68	22	67	65	—	—	67	—	—	96	69	70	66	—	—	155	155	—	—	—	—	1400	300	3	—
	11	196	16.5	—	—	83	74	76	16	76	21	75	74	—	—	69	—	—	98	71	72	76	—	—	155	155	—	—	—	—	1400	300	3	—
	2 P.M.	201	14.0	—	—	82	75	77	13	77	19	79	77	—	—	74	—	—	104	76	77	72	—	—	155	155	—	—	—	—	1400	300	3	—
	5	208	15.5	—	—	82	72	74	15	74	21	74	72	—	—	74	—	—	101	76	77	70	—	—	155	155	—	—	—	—	1400	300	4	—
NIGHT TURN	8	184	16.0	—	—	76	68	72	15	73	18	73	68	—	—	70	—	—	100	72	73	69	—	—	155	155	—	—	—	—	1400	300	4	—
	11	202	14.0	—	—	78	70	73	13	74	16	72	68	—	—	72	—	—	102	73	74	68	150	—	—	155	—	—	—	—	1400	300	4	—
	2 A.M.	200	13.0	—	—	76	67	71	12	71	15	68	65	—	—	70	—	—	98	71	72	67	150	—	—	156	—	—	—	—	1400	300	4	—
	5	180	14.0	—	—	72	60	70	13	68	15	67	64	—	—	70	—	—	98	71	72	65	150	—	—	155	—	—	—	—	1400	300	4	—
AVERAGES		199	15.0	—	—	78	69	73	14	73	18	72	69	—	—	71	—	—	100	72	73	69	150	—	155	155	—	—	—	—	1400	300	—	—

FOLDER No. 7

) Suppose, for example, the dust determinations of a certain day, of several consecutive days, show a much higher amount of im- ities in the engine gas than usual. Steps to remedy this condition be taken immediately. As a rule an increased amount of water ie preliminary washing plant, or on the Theisen washers, will have desired effect; or an additional washer can be started, thereby easing the load on each unit and giving the gas an additional bbing. Without the daily record, this increase in dust might not oticed until trouble arose in the engines; or a clogging of the wet bbers or of the gas flues might not be noticed until the effect of a icted gas passage was shown in the reduced output of the power it.

1 For example, on consulting the daily records in September and ober 1908, it was noticed that the gas pressure between the two scrubbers was considerably lower than that in the collecting flue, ate of affairs particularly annoying at that time as another period nsufficient gas supply was on hand. It was first thought that hurdles in wet scrubber No. 1 were clogged by dust bridging over ween slats. Simultaneous readings of the pressure gages on ier side showed a difference of 1 ¼ in. to 2½ in. After flushing the ibber for 30 minutes by opening wide all the top sprinklers and side h-outs, which are situated half way between the top and bottom the scrubber, and using 1800 gal. of water per min., this differ- e did not disappear, indicating beyond a doubt that no obstruc- n had occurred in the scrubber. It was finally found that the ubber inlet pipe was nearly filled with mud at the point where it ns at a slight angle into the wet scrubber shell and a heavy stream water soon removed the obstruction.

52 In March 1909 the amount of flue dust in the dry cleaned gas reased rather suddenly from 0.56 grains per cu. ft. on March 3 1.53 grains per cu. ft. on March 5. The amount of water on wet ubber No. 2 was increased from 400 to 500 gal., and decreased from 0 to 350 gal. per min. on the Theisen washers. The effect was a terial improvement in the wet scrubber efficiency, while the amount dust in the fine gas was hardly affected. This is illustrated in Fig. , showing the daily averages of the dust contents in the gas, etc. this manner the total amount of water for wet scrubbers and Thei- n washers as well as the relative quantities for scrubbers No. 1 and o. 2, were changed frequently during the year to conform with the mands indicated by variations in the recorded results. The methods d instruments used to obtain these records are given in Appendix d instruments used to obtain these records are given in Appendix o. 3.

RECORDS AND RESULTS OF OPERATION OF THE DRY-CLEANING PLA

63 Before the existence of the dry cleaning system at the b furnaces the two dry dust catchers in the preliminary gas-clea plant proved very satisfactory in operation and efficiency, and effect of unlined gas flues and dust catchers on the reduction in t perature of the gas was greater than had been anticipated. The t perature at which the gas leaves the furnace top averages about deg. fahr. with the furnaces in normal operating condition. temperature may, however, reach 700 and 800 deg. when abno conditions of operation are caused by high coke consumption, in lar working, etc., and furthermore when special grades of iron, su ferrosilicon or spiegeleisen are produced. When formerly all naces discharged their gas directly into the brick-lined overhea the temperature of the gas at the entrance of the gas-cleaning was considerably higher. Thus in 1908 the average temperature a main water seal, according to Bristol pyrometer records, was a lows in degrees fahrenheit:

March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
650	500	483	531	426	410	303	312	299	329

The drop in temperature of the gas, due to radiation of heat thr the walls of unlined piping and dry dust catchers, was quite nounced (see Appendix 4, Table 10). In round numbers about 5 cent of the sensible heat carried by the gas into the dry-cleaning was removed by radiation.

64 An attempt was made to determine the number of B radiated per hour per square foot of radiating surface of the dry catchers to obtain a basis for future calculations. For five diff days the B.t.u. loss per square foot of radiating surface per degre ference in temperature per hour was 1.29; 0.99; 1.105; 1.11; 1.33; an average for all observations of 1.165.

65 After the dry dust catcher system at the blast furnaces wa in operation conditions changed considerably, as the gas pa through the voluminous unlined dry dust catchers and the over gas main, the brick lining of which had been removed in April 1 lost so much heat by radiation that it entered the gas-cleaning p at a much lower temperature than before. This temperature is uniform at present, averaging about 300 deg. fahr. The heat-ra ing effect of the dry-cleaning plant, however, is maintained, redu the average temperature of the gas before it enters the wet-clea

t about 56 per cent, as shown in Fig. 26, which gives the average thly figures for 1909. Since the cooling effect takes place without use of water, it is obtained entirely without cost.

This cooling of the gas to a temperature considerably below 212 in 1909 caused heavy condensation of moisture in the pipes and

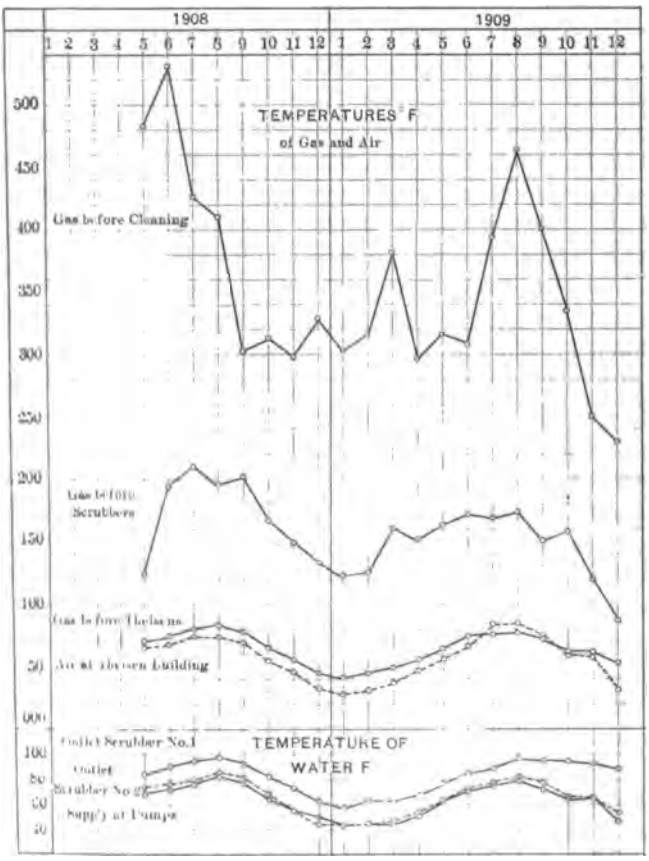


Fig. 26 Temperatures of Gas, Water and Air (Monthly Averages)

y dust catchers. This proved to be of considerable value in the ocess of gas cleaning, since the finer particles of dust were weighed wn by microscopical globules of water and thus more easily s pated from the gas. The dust removed in the dry cleaning plant appeared mostly in the form of mud, which accumulated at all points of

change in direction of the gas flow, and especially in the dry du catchers where the velocity was very small. The difficulties e countered in trying to remove this mud during the operation of t plant formed one of the reasons for abandoning the dry dust catch at the gas-cleaning plant. As outlined in Appendix No. 3, seve attempts to obtain reliable data concerning the dust-removing e ciency of the dry-cleaning plant proved futile, but an idea can gathered from the fact that on an average a carload of dry dust wei ing about twenty-five tons was removed every other week, whil large quantity was blown away by the wind.

67 The condition in which the gas was delivered to the next st of cleaning is shown in charts (Figs. 25, 27 and 28) and in Appen 4, Table 11, wherein the monthly averages as well as the daily va tions of the dust contents in the dry cleaned gas are given. Th curves and particularly Fig. 28, which gives the daily amount of dust in dry cleaned and clean gas for the period from August to cember 1909, drawn to a larger scale, indicate quite violent fluct tions which are due to different operating conditions of the b furnaces.

68 Heavy slipping will naturally increase the dust contents in raw gas beyond measure. It has an effect very similar to an explos as the sudden upheaval of the stock in the furnaces causes a mom tary rise in the gas pressure, illustrated on pressure chart Fig. 1. velocity of travel of the gas through the pipe lines after a slip can ea be observed in the rapidity with which clouds of flue dust belch fo from boiler stacks, nearly 1000 ft. from the source of disturba only a very few seconds after the slipping. Besides the moment increase in the quantity of dust caused by slipping the furna considerable amounts are added from the deposits of flue dust in p lines, dust legs and dry dust catchers, accumulated for hours days, and disturbed by the sudden high velocity of the gas.

69 The nature of the furnace product has a great deal of influe on the quantity of flue dust produced. While Bessemer and basic naces produce about equal amounts in the plant under discussi ferrosilicon and spiegel furnaces make very much more, which mo over is very fine and cannot easily be removed from the gas—esp ally not by dry cleaning alone. Thus for instance a sudden incre of 270 per cent in the dust contents in the dry cleaned gas occur in March 1909, due to the following cause: For several months p vious the raw material charged into the furnaces had been consid ably "watered" to reduce top temperatures and flue dust losses.

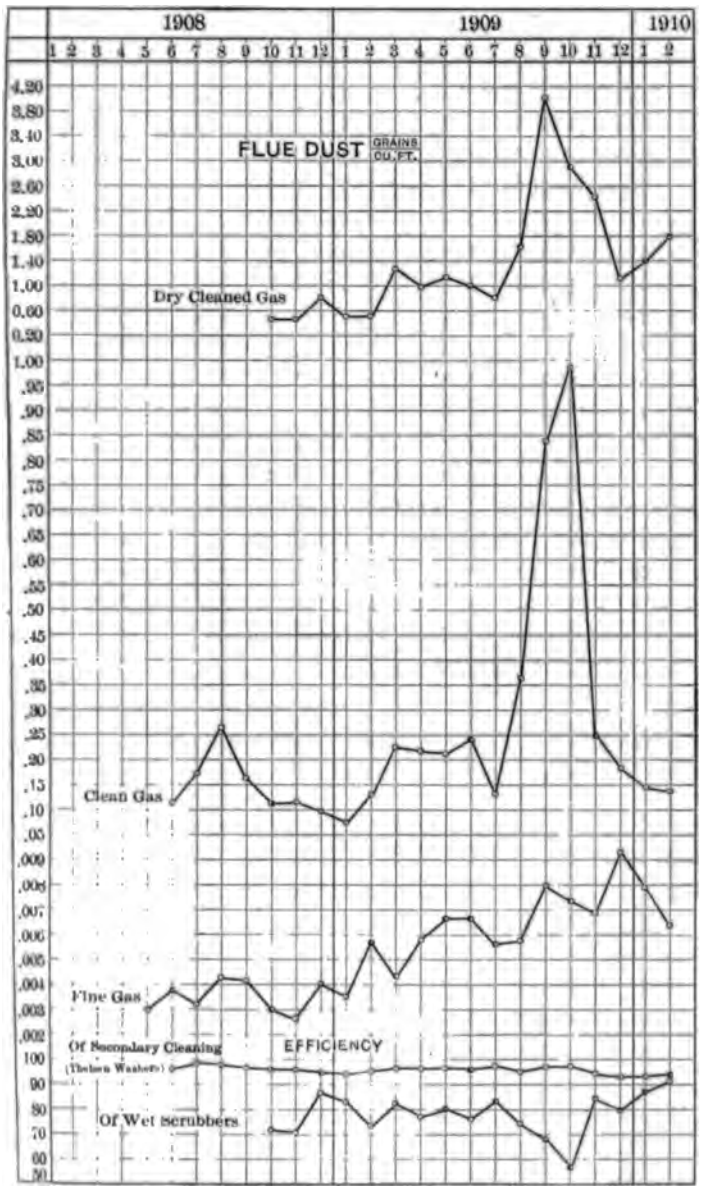


FIG. 27 FLUE DUST IN GAS AND EFFICIENCIES OF CLEANING PLANT (MONTHLY AVERAGES)

February 28, 1909, the watering of the stock was sudden
tinued. The result was an increase of nearly 100 per cent i
contents in the dry cleaned gas, as shown in Fig. 25. It begin
day ending March 4 and shows great fluctuation, while aft
24 a sudden decrease occurs and the amount of dust for the r
month shows considerably more uniformity.

70 The reduction was due to the fact that on March 24 t
ing of the stock was resumed in a moderate way. The averag
of flue dust in the dry cleaned gas in February was 0.478
against 1.2951 grains per cu. ft. in March, the corresponding
of dust in clean gas being from 0.1224 grains in February
grains per cu. ft. in March, or about 200 per cent. The qua
gas cleaned per minute were almost exactly the same, name
cu. ft. in February and 14,717 cu. ft. in March, so that th
are directly comparable. It cannot be estimated even, ho
dust the raw gas contained during March, but when the
catchers were opened for examination on April 3 it was fo
the mud in the bottom cones had accumulated to the
while large dust and mud deposits were discovered in th
even, the latter having lost its self-cleaning qualities du
nature of the deposits, which in their muddy condition re
slide down into the dust legs.

PERFORMANCE OF WET-SCRUBBING PLANT—COOLING AND CO EFFECT

71 The preliminary wet-scrubbing plant was particularly
ful and efficient, and the operation of the wet scrubbers
continuous ever since starting in November 1907. Several
tions of the wet scrubbers took place, at times when the g
station was shut down entirely, and it was invariably fou
both were in perfect condition. Aside from a thin coating
flue dust, which seems to have penetrated into the pores of th
there was no sign of any deposit on or around the hurdles
oxygen is almost entirely absent, rotting of the woodwork is
ble. From observations of the condition of the wet scrubbers
clusions may be drawn that it is unnecessary to be particular
ing the quality of lumber for manufacturing the slats and that
it all over could possibly be dispensed with. The distance
the slats could be made very much smaller than in the two
wet scrubbers, and a spacing of about three inches was ado

FOLDER No. 8

o new ones. No difficulties of any description were encountered operation of these scrubbers, and the overflow arrangement he water sealed basins, shown in Fig. 11*b*, as well as the disposal dirty washing water never caused any trouble.

In Fig. 26 and in Appendix 4, Table 12 are shown the effects cleaning upon the temperature of the gas and the corresponding and waste water temperatures. A comparison of the curves that the gas was cooled practically to water temperature, ecords show that this cooling action is nearly limited to the first rubber, as the temperature of the gas between the wet scrubbers nly a few degrees higher than the clean gas temperature. The ge tempe rature of the clean gas for the first half year was 54.7 while the temperature of water supply was 53.3 deg. for the same l. For the second half of 1909 these temperatures were 67.4 6.7 deg. respectively. The yearly average temperature of the gas was 61.1 deg., while the yearly average temperature of the supply was 60.0 deg. The temperature of the waste water scrubber No. 1 was on an average 20 deg. higher than the temure of the fresh water, while the water from wet scrubber No. 2 ot exceed the average water supply temperature more than 1.7 'ahr. The first wet scrubber naturally removed the bulk of the as was indicated by the muddy, black appearance of the waste r, but a good share of the cleaning was done by the second scrubudging by the reddish-brown color of the water discharged.

The cleansing efficiency of the wet scrubbers, that is, the of the amount of dust removed by the scrubbers to the total ınt which they receive is given in Figs. 25, 27 and 28 and in ndix 4, Table 11, which shows the amount of flue dust in clean with its daily and monthly variations. The average efficiency of vet scrubbers was nearly 80 per cent during the first, and 78.8 per during the second half of 1909, while the average yearly efficiency hed 79.3 per cent. The drop in the second half, and particularly eptember and October, is due to the ferrosilicon and spiegeleisen on blast furnace No. 1. If the relatively high amount of dust ıe dry-cleaned gas for the same period is considered, as well as the that silicious dust is exceedingly difficult to remove, this reduced iency is not surprising.

Of greatest interest is the effect of wet cleaning on the amount ıoisture in the gas. This information is given in Fig. 25 and Fig. While the quantity of water used at the wet scrubbers was conrable, averaging 82.8 gal. per 1000 cu. ft. of gas cleaned, the aver-

age amount of moisture in clean gas was only 6.62 grains per cu. ft. with a maximum of 13.243 grains in August and a minimum of 2.61 grains in April. By comparing these figures with the corresponding average amounts of moisture in atmospheric air, an interesting coincidence will be noted, as the maxima in both cases occurred in August while the minima obtained in April. In Appendix 4 are detailed results of tests made to determine the cooling and condensing effects of the wet scrubbers.

PERFORMANCE OF SECONDARY CLEANING PLANT

75 The Theisen gas washer installation in the secondary cleaning plant was very successful, both in regard to the mechanical operation and the cleaning efficiency of the washers. Theisen washer No. 1, started in 1907, was opened for examination on February 6, 1909,

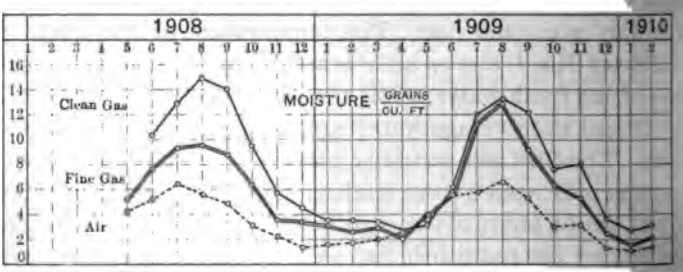


FIG. 29 MOISTURE IN GAS AND AIR (MONTHLY AVERAGES)

after about 7400 hours of operation. The condition of this washer was as follows: The drum was almost perfectly clean, the longitudinal vanes showing a coating of soft mud about ½ in. in thickness and 10 in. in length on the back side near the gas inlet. The total amount of mud and dust on the vanes when dried filled a 3½-gal. water pail twice, and, except to repaint the drum, the washer needed no attention. The paint was worn off the front of the vanes only, especially on the outer edges. The wear of the water on the longitudinal vanes, due to its velocity and its contents of granulated cinders, was quite noticeable at the points where the water happened to impinge. On account of a slight defect in construction and the inadvertent use of hard high-carbon steel in their manufacture, some of these vanes cracked along their rivet holes and needed replacing. Softer low-carbon steel has since been used and the longitudinal vanes were braced, as shown

g. 19, and this trouble has not again occurred. The wear in the itt-lined bearings allowed the shaft to lower about $\frac{1}{32}$ in.

The wire netting was absolutely clean, while somewhat cor- l in places on the bottom, and the claim that this washer is self- ing was fully substantiated by the examination. Theisen washer 2 was opened in March 1910 for its second examination after y 9300 operating hours, and its condition was found to be equally actory. The accumulations of mud were very slight as shown in

FIG. 30 THEISEN WASHER DURING EXAMINATION

30 and Fig. 31, photographs, taken immediately after removing op half of the casing. The washers can run continuously for ths without being shut down. except for occasional cleaning of notors. All smaller repairs on these washers, as well as on the le gas-cleaning plant, are made by the operators, and the expen- re for lubricants and other supplies is amazingly small.

The chart in Fig. 2 shows that the average gas pressure r the Theisen washers was only slightly in excess of the aver-

age raw gas pressure, the difference being about 3 in. of water column. The advantage of this slight pressure difference is obvious, in contrast with the considerably higher pressure given by so-called hydraulic fans. Superfluous pressure for the transmission of the gas to the point of consumption, must be paid for in excess power. The gas temperature at the Theisen washer inlet was practically water temperature, while the temperature of the gas delivered by the Theisen washers was found to be on an average 2 deg. to 3 deg. higher, a difference

FIG. 31 THEISEN WASHER—DETAIL OF DUST DEPOSIT

explained by the fact that the mechanical work consumed by the Theisen washers must be transformed into heat, which in portion is imparted to the gas. On its way to and in the gas holder this heat is again radiated, so that the gas temperature at the engines practically equals the temperature of water supply, and only a little difference can be observed between the atmospheric temperature and the temperature of the fine gas (see Fig. 26).

The performance of the Theisen washer as a gas cleaner, con-
ing the variety of conditions of furnace operation, was beyond
ach. By referring to the daily and monthly averages, given in
e 13, Appendix 4 and plotted in the charts in Fig. 25 and Fig.
t will be noted that the efficiency of the secondary cleaning plant,
is, the ratio of the amount of dust removed by refining to the
amount contained in the clean gas leaving the preliminary wash-
lant, averaged 98.1 per cent. While this figure in itself is remark-
it is of much more importance that this efficiency, as shown by
lose coincidence of the monthly average figures, was exceedingly
rm, varying from a maximum of 99.1 per cent in October, to a
num of 95 per cent in December 1909. The average efficiency
e first half-year was 97 per cent, while the corresponding figure
he second half reached 98.7 per cent. The great variations to
h the amount of flue dust in dry-cleaned gas was subjected during
ear, especially however in March and April and during the period
the latter part of August until the middle of December, did not
cularly affect the efficiency of the secondary cleaning plant, since
ptember and October, when the amount of flue dust in dry
ed gas averaged 3 to 4 grains per cu. ft., the efficiency of the secon-
washing plant shows a very marked uniformity—the average
August 25 until November 5 being 98.87 per cent—while the
ncy of the wet scrubbing plant gradually decreased from 83
ent in July to 75 per cent in August, 69 per cent in September,
57 per cent in October. The amount of flue dust in fine gas dur-
hese months was, of course, higher than in any previous period,
the efficiency of refining was nearly a constant maximum, irre-
tive of the dust conditions of raw and clean gas and of the quality
e flue dust.

During September and October, when furnace No. 1 made its
silicon run, the color of the waste water from wet scrubbers and
isen washers was very milky, and the dust so high in quantity,
so peculiar in quality, that considerable accumulations occurred
he clean gas main and at the inlet gate valves of the Theisen
her. The silicious flue dust seemed to set like cement, and
ps of considerable size and of great hardness had to be removed
h a bar, from the inlet gate valves of the Theisen washer. Never-
less the efficiency of the secondary washing plant during these
o months was higher than during any other period.

In the previous paragraph the term "efficiency of the second-
y cleaning plant" was used deliberately in order to indicate that in

this remarkable showing gas mains and gas holder participated. The clean and fine gas flues, connecting wet scrubbers, Theisen washers and power station gas holder, have a combined length of approximately 1000 ft., and a diameter of 5 ft. 6 in. and 5 ft. respectively. The total quantity of gas passing these mains per minute averaged 16,900 cu. ft., with a maximum of 20,300 cu. ft. in October, and a minimum of 13,600 cu. ft. in January. The velocity of the gas while traveling through these pipes did not exceed therefore 14 ft. per sec. in the clean gas main, and 17 ft. per sec. in the fine gas main. At this low velocity some impurities will undoubtedly drop out in the clean gas main, with the finely divided water which is carried along by the gas. The fine gas main, however, was always found practically clean; and while an examination of the gas holder tank has not been made, it is not believed that any great quantities of flue dust would be found in the bottom of the tank, as the dust in the fine gas is so impalpable that the fine gas burns with an absolutely clear blue flame. However, in order not to credit the Theisen washers alone with removing 98 per cent of the dust from the clean gas, the efficiency is stated as embracing the secondary washing plant as a whole, or the combination of gas pipes, Theisen washers, water separators and gas holder.

81 That the Theisen washers must be credited with the bulk of the work is proven by the test summarized in Table 14, Appendix 4. From the results given it will be seen that the efficiency of the clean gas main averaged 16.5 per cent while the fine gas main and the gas holder removed only 6 per cent of the dust delivered by the Theisen washers, or 0.23 per cent of the dust in the clean gas, proving that but little cleaning is done by gravity and reduced velocity. The Theisen washers had nearly 95.5 per cent absolute efficiency during the week when the tests were made, while their relative efficiency, based on the amount of dust in clean gas, was 79.64 per cent. It is safe to assume that similar conditions prevailed during the year 1909 and that the same relative proportions hold true at any time. The inconsistency in some of the results obtained after the Theisen washers and after the gas holder, which would indicate the impossible condition that the gas picked up a certain amount of dust on its way from washers to holder, is due to the small quantities on the shell of the Brady filter, which have to be dealt with in fine gas and cause errors in observations.

82 Since starting the gas power plant in 1907 the absolute amount of dust in the fine gas naturally continued to increase gradually, corresponding to a similar increase in the amount of gas cleaned per

inute, shown in Fig. 32. At the beginning of operations the gas ıgines received gas of a degree of cleanliness excessive for practical ırposes. Thus the average dust contents in the fine gas in the second alf of 1908 was only 0.0036 grains per cu. ft., or 0.0077 grams per cu. ., which is much less than the average usually guaranteed. An ccessive purification of blast furnace gas, even for engine purposes, unwarranted, because the atmosphere in a steel plant is usually ery dirty, and it seems quite out of place to purify the gas to a higher egree of cleanliness than the combustion air, unless the latter is to e subjected to a similar cleaning process. Tests made in July 1909) determine the quantity of impurities contained in the air near the ir intake of the gas engines showed the amount to be between 0.0005 nd 0.0052 grains per cu. ft. with an average of determination (given in

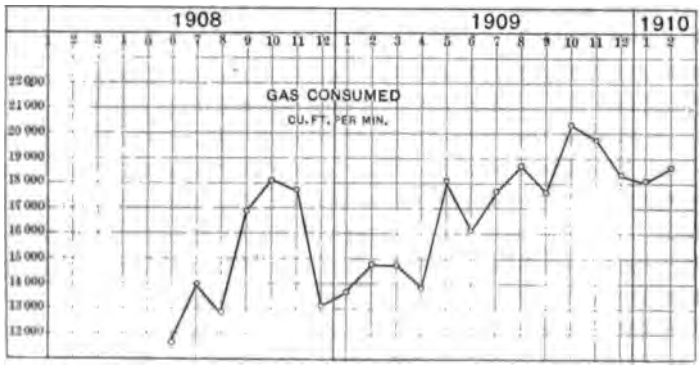


FIG. 32 GAS CONSUMED, CU. FT. PER MIN. (MONTHLY AVERAGES)

Table 15, Appendix 4) of 0.00346 grains per cu. ft. The amount of dirt n the air is therefore by no means a negligible quantity. The detrimental character of these impurities is also apt to be underestimated. In Appendix 4, Table 16 is a comparison of the chemical analyses of samples of the deposit on the gas and air dampers in one of the gas engines, taken in February 1909. It is to be noted that the gas never comes in contact with the air dampers, so that the samples fairly represent the accumulation of dirt deposited by the combustion air.

83 A comparison of the four analyses shows the surprising fact that the amount of iron in the dust sample taken from the air dampers is about twice as great as in the dust deposited on the gas dampers. If this is true—and there is no room for doubt, as the samples represent the accumulations of more than one year, the dampers never having

been cleaned—it follows that appreciable quantities of iron, sand and coke enter the engines with the combustion air.

QUALITY OF FLUE DUST

84 The chemical composition of the flue dust removed from the gas at various stages of the cleaning process was made the subject of analysis in March 1908. Samples were taken at the following points: dry deposit from the main water seal and collecting flue after dry dust catchers, suspended matter secured by evaporation of samples of the waste water from wet scrubbers No. 1 and No. 2 and the Theisen washers. The results of this test are shown in Table 17, Appendix 4, all analyses giving metallic iron and manganese as Fe and Mn, while the constituents exist in the form of oxides. Fixed carbon is mostly coke, and the volatile matter is the CO_2 from limestone. This table shows that the relative amounts of silica, alumina, lime, etc., increase gradually, more and more of the heavy impurities such as Fe dropping out the further the cleaning process progresses.

85 A similar test was made in March 1910, with the difference, however, that there was an attempt to determine the quality of the dust remaining in the gas while passing the various stages of gas cleaning. In this case the method of securing samples consisted in connecting Brady filters at the various points and turning the gas on simultaneously at all filters. Irrespective of the size of the gas sample, the cartridges were not removed until sufficient quantities of dust had collected for quantitative and qualitative analyses. It was impossible to obtain a sufficiently large sample for analysis on the Brady filter installed after the Theisen washers, for while the filter passed the gas very rapidly for a few hours, the flow gradually diminished as the dust in the fine gas closed up the pores of the paper. After a 36-hr. run the flow through the filter had stopped completely and the dust collected on the Soxhlet tube appeared as a dull gray coating, which could not be removed. The results of this experiment are given in Table 18, Appendix 4.

86 The relative amount of SiO_2 carried in the gas is practically constant before any wet washing takes place, but the percentage increases in the clean gas, with decreasing relative contents of iron. The wet scrubbers remove the bulk of the iron dust, while the lighter impurities are carried over into the Theisen washers. A sample of the dust deposited in the gas pipe on one of the gas engines immedi-

tely before the gas enters the cylinders at the end of its travel, taken March 15, 1910, was analyzed as follows:

SiO_2	Al_2O_3	Fe	CaO	MgO	Mn	Vol.
36.20	7.53	7.18	12.50	0.90	0.49	34.32

The high percentage of silica, lime and volatile matter, and the very low contents in iron are noteworthy, and show that silicious dust, lime and coke are carried by the gas much farther than iron, which is removed to the greatest extent in the first stages of cleaning.

87 Due to sulphur in the coke, blast furnace gas contains a certain amount of this impurity in the form of H_2S and SO_2. Its pres-

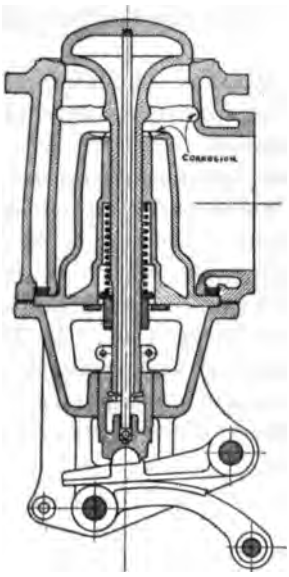


FIG. 33 CORROSION OF VALVE CASING BY SULPHUR IN GAS

ence was discovered after some length of operation of the gas engines. It was found that several of the exhaust valve casings showed very pronounced corrosion, at a place indicated in Fig. 33 and it was concluded that some chemical action had taken place. Two tests made Feb. 2, 1909, showed the presence of 0.0416 and 0.0407 grains per cu. ft. of sulphur in the gas. It was further discovered that the fine flue dust accumulating in thin layers in the gas passages to the engine cylinders, can be lighted and glows with a blue color, unmistakably giving out SO_2 vapors. The corrosion in the exhaust valve chambers was caused by water leaks from the original inner exhaust valve guides,

which cracked as indicated in the illustration. The water coming in contact with the hot exhaust gases formed H_2SO_4, which impinging on the wall of the exhaust valve chamber, had the corrosive effect. The presence of sulphur in blast furnace gas for this reason prohibits the use of sheet-iron exhaust pipes and mufflers, while corrosion has never been observed when cast iron is used. It was attempted, some time ago, to utilize the waste heat from the exhaust of these engines to raise low-pressure steam for use in the heating system of the power house, in wrought-iron pipe coils arranged inside the cast-iron mufflers, and while the results were very satisfactory from the standpoint of heat transmission, this heating system was a failure on account of the rapid corrosion to which the heating coils in the mufflers were subjected.

88 The amount of moisture remaining in clean gas, fine gas and air, as well as the variation from day to day and from month to month, are shown in Figs. 25 and 29.

89 While the Theisen gas washers receive the gas at practically water temperature, so that a condensation of water vapors by cooling is improbable, the amount of moisture in the engine gas is nevertheless lower than in the clean gas, and this in spite of the exceedingly intimate contact between gas and washing water in the Theisen washers. The indications are therefore that the Theisen washers remove not only dust, but moisture as well, probably by the action of centrifugal force, which throws gas and water vapors against the circulating water film on the inside of the stationary casing, thereby drying the gas mechanically. Furthermore a great deal of moisture is being deposited in the fine gas main and gas holder. The average moisture in the gas delivered to the engines was 3.39 grains for the first half, and 7.85 grains for the second half of 1909, with a yearly average of 5.62 grains per cu. ft. Comparing these figures with the corresponding values in clean gas and atmospheric air, it will be seen that the average moisture in the engine gas for the year is 60 per cent higher than the average moisture in the atmosphere, which is considered very favorable in view of the high moisture contents in raw gas and the large quantity of water which is brought into such intimate contact with the gas.

90 The effect of the sun beating down on gas mains and gas holder is very noticeable in the summer months, accounting for the high moisture contents in July, August and September. Pipes and holder become quite hot and the finely divided mist in the gas is rapidly evaporated, as indicated by a drip installed near the venturi meter.

s or small streams of water are freely discharged in the winter hs, while the dripping ceases as soon as the atmospheric tem- ıure exceeds about 78 deg. fahr. The moisture carried with the ıto the engine cylinders has not given cause for trouble at any

WATER AND POWER CONSUMPTION OF CLEANING PLANT

Fig. 34 shows the average monthly consumption of water July 1908 in gallons per 1000 cu. ft. of gas cleaned, as estab-

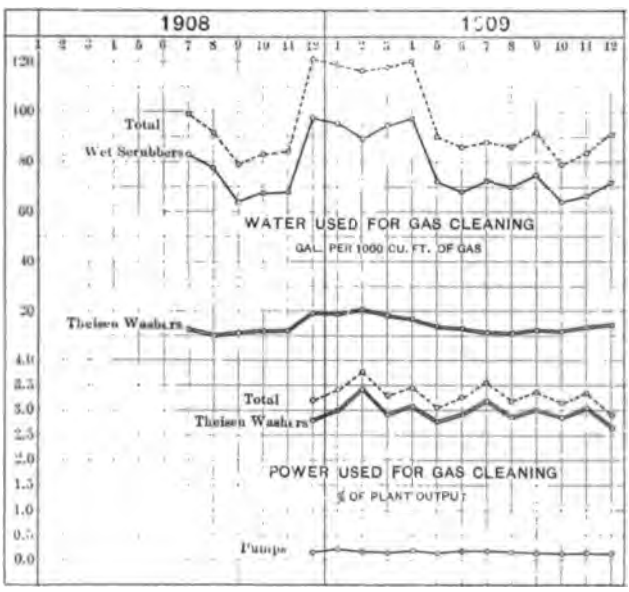


Fig. 34 Water and Power Consumption of Gas-Cleaning Plant

d from daily weir measurements. It is to be noted that the r consumption of the wet scrubbers is about four times as high hat of the Theisen washers, for the same quantity of gas cleaned. latter varied from 26.1 gal. in February to 16.0 gal. in July, with ıverage of 21.8 gal. for the first and 17.0 gal. for the second half, 19.4 gal. per 1000 cu. ft. of gas for the whole year. The corre- ıding figures for the wet scrubbers were a maximum of 103.2 gal. ıpril, and a minimum of 68.6 gal. in October, with an average of) gal. for the first half, 74.6 gal. for the second half, and 82.8 gal. 1000 cu. ft. for the year 1909.

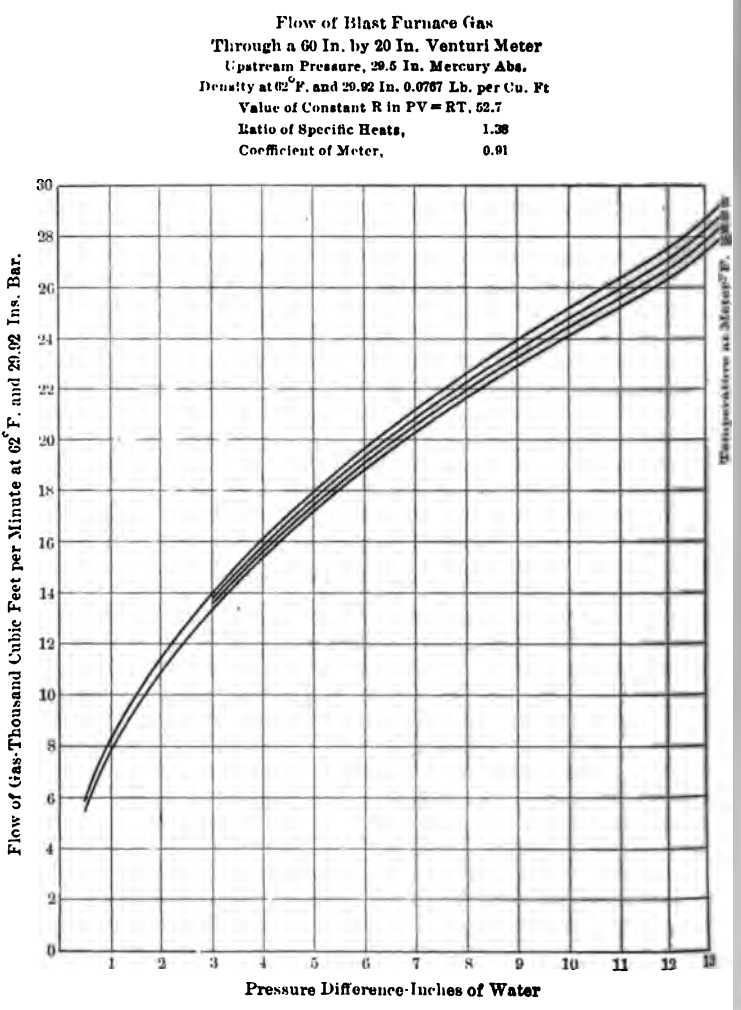
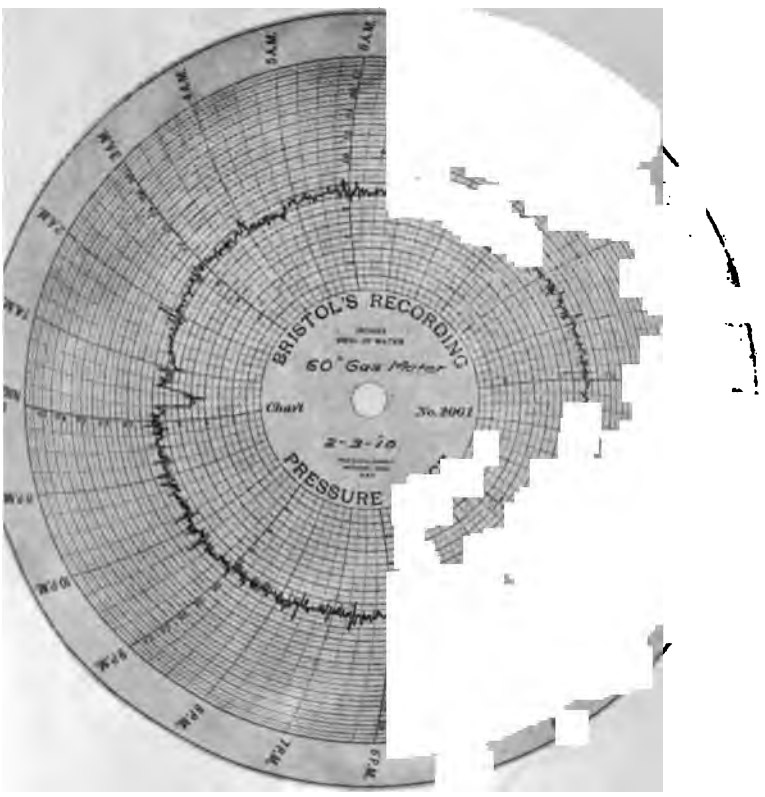


FIG. 35 VENTURI METER CURVES SHOWING FLOW OF GAS FOR DIFFERENT METER READINGS

92 The high water consumption in the first part of the year is due to the smaller quantity of gas cleaned. About the same absolute quantity of water was maintained on the scrubbers. Generally speaking, the quantity of water used in the wet scrubbers could probably be reduced without impairing their efficiency, but it is preferred to use water in excess rather than to run the risk of clogging the sewers, especially since the question of economizing washing water is of no particular importance in a plant located on the lake front.

)3 In regard to the amount of power required by the gas cleaning nt, Fig. 34 shows the monthly average power consumption of wet ubber pumps and Theisen washers, expressed in per cent of the tput produced by the gas engines. About 90 per cent of the total wer is being used by the Theisen washers, only 10 per cent being



. 36 BRISTOL CHART OF PRESSURE DIFFERENCES, 60-IN. VENTURI METER

cessary to operate the wet scrubber pumps. The average power nsumption of the Theisen washers was 2.977 per cent of the total tput of the station, and the respective values for the first and second lves of 1909 were 3.00 per cent and 2.931 per cent, with a maximum 3.44 per cent in February and a minimum of 2.649 per cent in ecember.

94 These figures are somewhat higher than are often claimed for similar washers abroad, but an average power consumption for the gas-cleaning plant, of from 3 per cent to 3.5 per cent of the total power output of the gas engines, should not be considered excessive in view

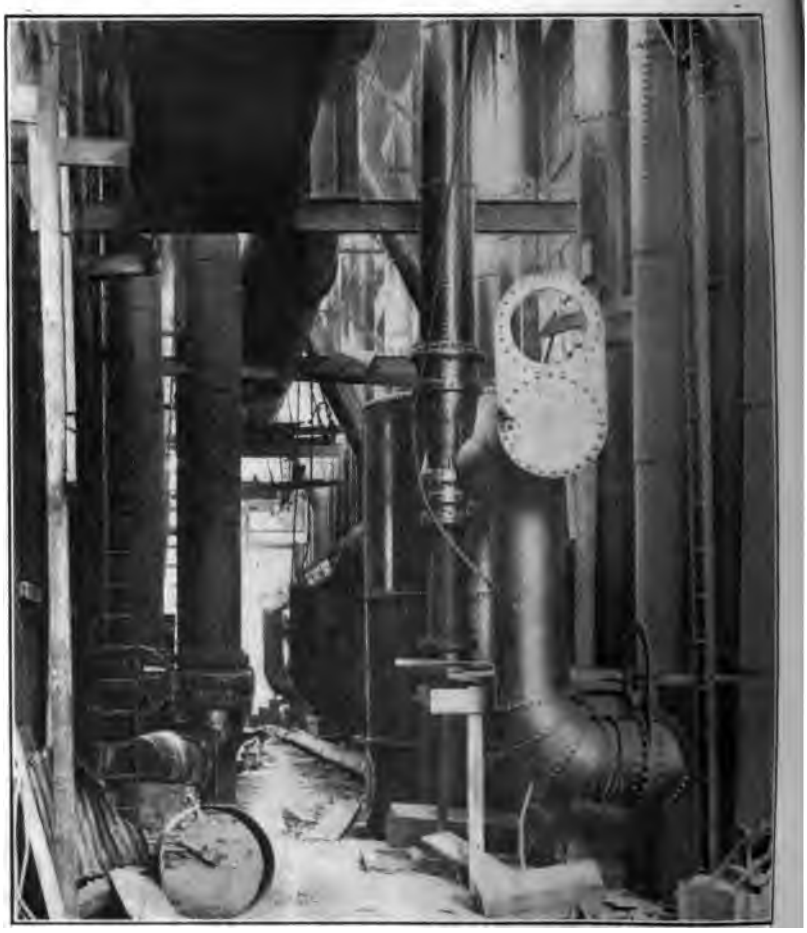


FIG. 37 EXTERIOR VIEW OF TEST PIPING

of the benefit which is being derived from this expenditure. It is worthy of note also that the engine builders who furnished the gas engines for the plant under discussion have never found fault with the physical condition of the gas, while more or less vigorous com-

laints about "excessive dirt" in the gas are generally advanced as oon as trouble develops in the engines. The necessity of auxiliary nachinery is furthermore not characteristic of gas engine installations lone, as boiler-feed pumps, hot-well pumps, dry-air pumps, forced-raft ventilators, mechanical stokers, etc., are indispensable for steam ngine plants consuming probably as large a percentage of the power leveloped.

95 It has been shown in the previous pages that the blast furnace as was delivered to the gas engines in a highly satisfactory physical ondition. The gratifying results of the thorough cleaning and refin-ıg of the gas were that no difficulties which might have been caused y insufficiently cleaned gas were ever experienced in the operation f the gas engines, and these engines never had to be stopped for the ecific purpose of cleaning internally the gas valves and gas pas-ages. The amount of dust deposited on internal engine parts was ıvariably so small that it could be brushed off with the finger, nd these engines could undoubtedly operate at full-load capacity whole year and longer without cleaning the gas inlet passages and ylinders.

96 Blast furnace gas delivered to the power house is charged to peration of the engines at a value based on the price of coal with the ost of cleaning and refining added to the value of the raw gas, which ı established on the basis of equivalent heat values. In order to etermine the charge made for purified blast furnace gas delivered o the gas power plant, a continuous record is being kept of the quan-ity of gas flowing to the gas holder, venturi meters being used as neasuring instruments. Details of the methods are given in Appen-lix No. 5. Charts relating to meter measurements are shown in Figs. 35 and 36.

THERMAL EFFICIENCY AND OUTPUT OF GAS ENGINES

97 It seemed desirable in connection with the installation of six gas blowing-engines, furnished by three different manufacturers, to provide means for determining the thermal efficiency of each type of engines without interfering with the regular operation of the others. To this end a special venturi meter was installed and connected to a "test" pipe, shown in Figs. 23*a* and 37. By opening the disc valve located inside the overhead gas receiver, which controls the flow of gas through the venturi meter into the large reservoir for equalizing pulsations caused by the intermittent suction strokes and test pip-ing, and by turning one small spectacle valve while simultaneously

shutting off the direct gas supply from the overhead receiver by filling the water seal, any engine can be operated on measured gas while the others receive gas directly through the branch pipes. Such tests can be commenced at any convenient time, and prolonged and repeated at will. A Bristol differential pressure recorder installed in the blowing-engine room gives continuous records of each test, so that reliable averages can be obtained of the gas consumption under different operating conditions.

98 Fig. 38 shows the monthly averages of the kilowatt output of the power station, of the heat consumption in B.t.u. per kw-hr. and per b.h.p-hr. based on a generator efficiency of 96.2 per cent at full load, and of the thermal efficiency. The diagram also shows the total operating time of each engine since starting.

99 The thermal efficiency of the plant was very uniform from the middle of 1908 until about May 1909, averaging 23.22 per cent. The drop which began in May and reached a low value in October, was due to certain troubles encountered with gas cylinders and piston rings, etc. These could not be remedied at that time, as on account of the ever-increasing demand of electric power and the lack of a spare unit, it was impossible to shut the gas engines down sufficiently long for a thorough overhauling and for necessary repairs. Doubtless with an additional spare engine the load factor would have been lower than the average for 1909, which reached 72 per cent, but the thermal efficiency would have remained constant—or nearly so—since the necessary repairs, adjustments and changes could have been made on these engines in time, without reduction in the total kilowatt output of the power plant. In spite of this reduced efficiency in the second half of 1909, the average figure obtained for the whole year—not as the result of one or of several individual tests, but as the fair average of daily observations, proper corrections having been made for the inexact readings caused by dust in the venturi meter in September and October—was 20.8 per cent, with a maximum monthly average of 23.77 per cent in March, and a minimum of 17.8 per cent in October. The highest daily average efficiency in 1909 was 25.7 per cent on March 11.

100 During the year 1909, the engines, while in operation, ran at nearly full-load capacity, the average for the four engines ranging from 93.60 to 99.63 per cent.

101 The values of the total kilowatt output of the gas power plant for each month since regular operation was begun, are plotted in Fig. 39, showing that the maximum output for any month occurred in

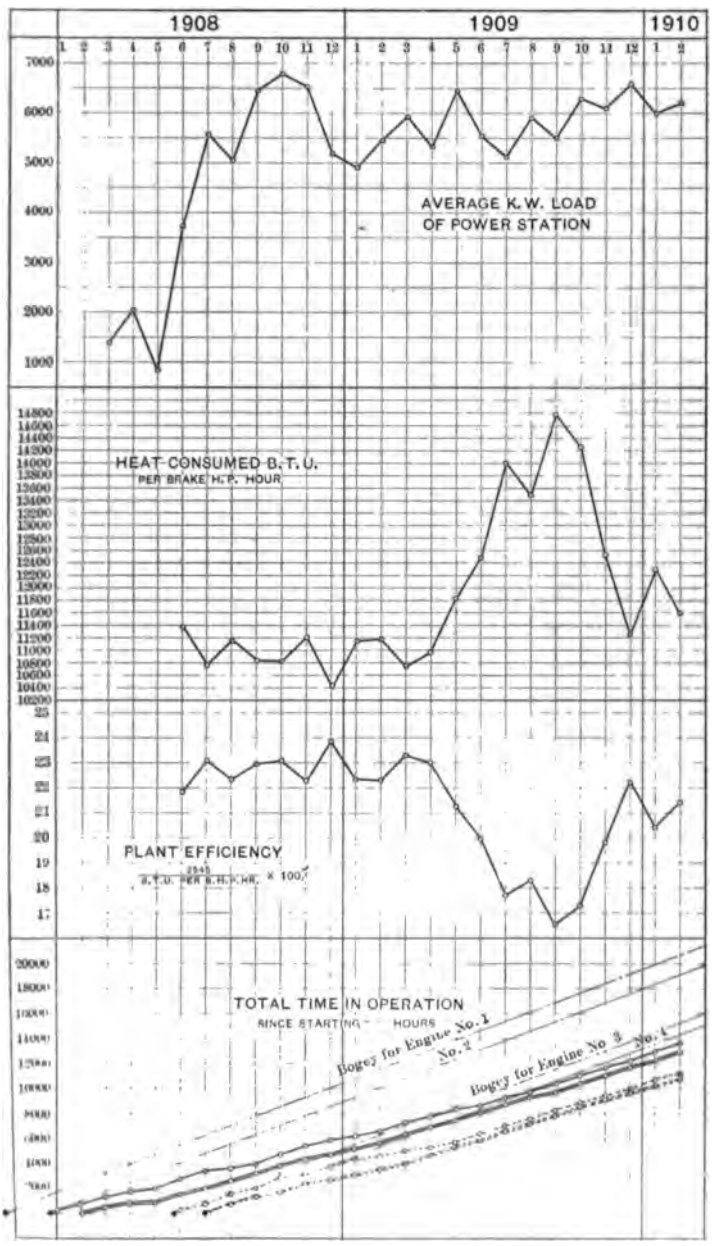


FIG. 38 AVERAGE LOAD, HEAT CONSUMPTION, PLANT EFFICIENCY AND OPERATING TIME (MONTHLY AVERAGES)

October 1908, when 5,000,000 kw-hr. was produced. The output of the gas power plant for the year 1909 was 50,494,100 kw-hr. against 43,953,640 kw-hr. produced by the steam-driven generators. The load factor for 1909 of the gas power plant was 72 per cent, against

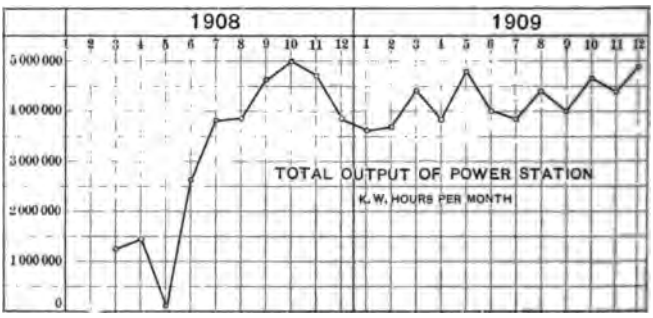


FIG. 39 TOTAL OUTPUT OF GAS POWER PLANTS (MONTHLY AVERAGES)

47 per cent for the steam power stations, which have a rated capacity of 10,900 kw. The total output of electric power generated in 1909 was 94,447,740 kw-hr., 53.5 per cent of which was produced by the gas power plant.

APPENDIX NO. 1

THLY RECORDS OF THE POWER PLANT (8000 KW.)

MONTHLY RECORD OF KILOWATTS PRODUCED PER HOUR

Month 1909	Kw. per Hr.	Per Cent of Capacity	No. of Furnaces in Blast
.....	4920	61.5	3
.....	5450	68.0	3
.....	5940	74.0	2
.....	5330	66.5	2
.....	6440	80.5	3
.....	5550	69.0	4
half.....	5600	70.0	
.....	5140	64.0	5
.....	5930	74.0	5
.....	5500	68.5	6
.....	6270	78.0	6
.....	6080	76.0	5
.....	6600	82.5	5
nd half.....	5920	74.0	
.....	5760	72.0	

TABLE 3 MONTHLY RECORD OF OPERATING TIME

1909	Plant in Operation		Plant down			
			Due to engines		Due to outside causes	
lonth	Hr.	Per Cent	Hr.	Per Cent	Hr.	Per Cent
.....	427	57	213	28.5	105	14.5
.....	456	68	85	12.5	131	19.5
.....	529	71	97	13.0	118	16.0
.....	467	65	170	23.5	83	11.5
.....	609	82	73	9.5	62	8.5
.....	556	77	97	13.5	67	9.5
t half.....	507	70	123	17.0	94	13.0
.....	607	82	103	14.0	36	4.0
.....	594	80	131	17.5	19	2.5
.....	595	83	107	14.5	18	2.5
.....	668	90	52	7.0	24	3.0
.....	632	88	65	9.0	23	3.0
.....	609	82	52	7.0	83	11.0
nd half.....	617	84	85	11.4	34	4.6
9.....	562	77	104	14.2	64	8.8

TABLE 4 MONTHLY RECORD OF LOSSES DUE TO OUTSIDE CAUSES

Month 1909	Plant down			
	Due to operation		Due to lack of gas	
	Hr.	Per Cent	Hr.	Per Cent
January	6	5.5	99	94.5
February	43	33.0	88	67.0
March	36	30.0	82	70.0
April	17	20.0	66	80.0
May	61	98.5	1	1.5
June	59	88.0	8	12.0
Average for first half	37	39.5	57	60.5
July	36	100.0	..	....
August	19	100.0	..	....
September	15	83.5	3	16.5
October	24	100.0	..	....
November	23	100.0	..	....
December	78	94.0	5	6.0
Average for second half	33	97.0	1	3.0
Average for 1909	35	55,0	29	45.0

APPENDIX NO. 2

A UPON GAS PRODUCED IN THE BLAST FURNACES

ETHODS OF CALCULATION OF QUANTITY OF GAS PRODUCED

"nitrogen method" assumes that the nitrogen in the air, amounting cent by volume, passes through the blast furnace unchanged, so me quantity must be found in the exit gas of the furnaces. Since gas composition is known, the percentage of nitrogen can be deter- ifference. The amount of air blown is based upon the revolutions of engines corrected for volumetric efficiency of the blowing tubs and it assumed loss of air between tubs and tuyeres. Thus, for instance, 909 blast furnace No. 6 produced on natural blast a daily average of f Bessemer iron, using 37.5 per cent Pocahontas and 26.5 per cent le coke with an average coke consumption of 2148 lb. per ton of average gas analysis for the same month was as follows:

CO	H	CH_4	N (by difference)
25 28	4.65	0.23	55.61

. per cu. ft. at 62 deg. fahr. = 96.8
. per cu. ft. including sensible heat at 500 deg. = 105.3
perature of air at blowing engines = 94 deg. fahr.
t. of air blown per min. = 40,990
t. of air blown per min. at 62 deg. fahr. = 38,610
age blast pressure = 15.1 lb.
t. of air to furnace per min. including 5 per cent loss at 62 deg. ahr. = 36,690
me of gas per volume of air at 62 deg. N unchanged = 1,426
t. of gas per minute N method = 52,300
to this calculation No. 6 furnace produced about 153,000 cu. ft. on of pig iron made in 24 hr.

nitrogen method, however, is subject to serious errors from the moisture and foreign gases in the air as blown, and from air leak- fficiency of tubs. The "carbon method," which is considered more sumes that the carbon entering the furnace in the form of coke, must the form of gas, the amount of carbon in the limestone being equal tely to that in the iron and slag. If A = per cent of carbon in the rged, B = lb. of carbon in 1 cu. ft. of blast furnace gas, the amount

$$\text{uced in cu. ft. per min.} = \frac{\text{tons of iron per day}}{1440} \times \frac{\text{coke rate}}{B} \times A.$$

the amount of gas according to this method, furnace No. 6 liber- cu. ft. of gas per min., or 149,000 cu. ft. per ton of product in 24 hr.

TABLE 5 DISTRIBUTION OF GAS FROM BLAST FURNACE NO. 6

August 1909

	Million B.t.u.	Per Cent
Total gas generated	324.1	100
Stoves and leakage	130.0	40
Blowing engines	92.1	28.4
Used at furnace	9.0	2.8
Auxiliaries	4.6	1.4
Total used for blast furnace operation	235.7	72.6
B.t.u. surplus for furnace	88.4	27.4
B.h.p. equivalent of surplus 1470		

104 The results of nitrogen and carbon methods do not, however, always agree as closely as in this instance. The average coke analysis for the month of August, from which the amount of carbon charged into the furnace was determined, was as follows:

	Per cent moisture	Per cent fixed carbon (dry)
Pocahontas	2.64	90.10
Connellsville	1.94	87.38

105 For the distribution of gas it is assumed that 40 per cent goes to the stoves and is lost by leakage. The amount of gas used for the blowing engines is calculated from the boiler horse power, the latter being determined by the quantity and pressure of air blown, the steam rates of engines and the evaporation per boiler horsepower. The B.t.u. equivalent of boiler horsepower for steam distribution in the current month is equal to $\frac{\text{boiler h.p.} \times 33{,}320}{\text{boiler efficiency}}$ and the latter is arbitrarily assumed to be 55 per cent. It is further assumed that 150 boiler h.p. is used in steam at each blast furnace and that all auxiliaries use 5 per cent of the steam going to the blowing engines. The difference is the surplus gas per furnace available for other departments, which is stated in the equivalent of boiler horsepower. Using the former example for an illustration, the total amount of B.t.u. in the gas produced per hour by furnace No. 6 was in August 1909, according to the carbon method, 324.1 million. The distribution was as above in Table 5.

106 The surplus gas was used for operating gas engines in the gas electric station and for raising steam for steam electric power. In this way a B.t.u. balance can be made for all furnaces in each month, as the total kilowatt-hours produced in the electric stations and the amount of coal which had to be fired under the boilers are known.

TABLES RELATIVE TO BLAST FURNACE GAS

TABLE 6 GAS PRESSURES

MONTHLY AVERAGES, INCHES OF WATER

	Jan.	Feb.	March	April	May	June	Jan. June Average	
t..	5.0	5.7	7.3	7.6	7.1	7.6	6.7	
...	8.0	8.0	10.1	9.4	9.7	9.8	9.2	
bes								
...	29.44	29.24	29.21	29.36	29.31	29.40	29.33	
	July	Aug.	Sept.	Oct.	Nov.	Dec.	July Dec.	Jan. Dec.
:..	9.1	10.0	12.0	13.4	14.6	13.2	11.9	9.29
...	11.9	15.0	13.9	16.5	17.7	14.8	14.9	12.10
ves								
...	29.34	29.37	29.44	29.45	29.42	29.41	29.45	29.37

BLE 7 COMPOSITION OF GAS FROM INDIVIDUAL FURNACES

AVERAGES

No.	CO_2	CO	H	$\frac{CO}{CO_2}$	B.t.u.	Product
.....	4.36	33.71	3.41	7.75	120.4	Ferro-Silicon
....	13.47	26.34	4.43	1.95	96.7	Basic
....	14.98	23.97	4.43	1.60	91.4	Basic
....	13.91	24.99	4.10	1.79	94.1	Basic
....	14.17	25.61	3.85	1.81	95.5	Bessemer
....	13.65	25.32	4.26	1.85	95.7	Bessemer

COMPOSITION OF MIXTURES OF GAS FROM VARIOUS FURNACES

AVERAGES

No.	CO_2	CO	H	$\frac{CO}{CO_2}$	B.t.u.	Product
.....	8.92	30.02	3.92	4.85	108.5	.....
.. ..	10.60	28.01	4.09	2.65	102.8	.....
	14.12	25.10	4.32	1.80	94.1	Basic
.	11 68	27.25	4.09	2.33	100.6	.....
.	14.23	25.15	4 43	1.81	94.0	Basic
6	12 25	26 66	4 08	2.23	98.9	.....

TABLE 9 AVERAGE COMPOSITION OF BLAST FURNACE GAS

AT 62 DEG. FAHR. AND 30 IN. MERCURY

	Jan.	Feb.	Mar.	Apr.	May	June	Avg. Jan.-June
CO_2	13.26	13.38	11.53	12.43	13.10	13.20	12.81
CO	25.61	25.50	28.10	26.67	26.56	26.50	26.49
H	2.99	3.95	2.92	3.16	3.74	3.89	3.44
CH_4	0.21	0.23	0.24	0.21	0.22	0.18	0.215
Computed B.t.u.	93.04	95.70	100.50	98.81	97.70	98.20	97.33
Ratio $\frac{CO}{CO_2}$	1.93	1.90	2.43	2.15	2.02	2.00	2.07
Heat value per cu. ft. by Calorimeter B.t.u.	93.45	96.10	101.00	98.08	98.32	97.99	97.49

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Avg. July-Dec.	Avg. Jan. Dec.
CO_2	14.10	12.50	10.03	0.21	13.88	13.75	12.88	12.8
CO	25.90	27.30	29.80	102.90	24.70	25.85	26.54	26.5
H	3.86	4.06	3.77	2 17	3.59	3.98	3.78	3.5
CH_4	0.17	0.18	0.19		0.19	0.15	0.18	0.1
Computed B.t.u.	95.70	101.40	108.70		86.70	95.80	98.46	97.8
Ratio $\frac{CO}{CO_2}$	1.83	2.18	2.98	2.17	1.78	1.88	2.12	2.0
Heat valve per cu. ft. by Calorimeter B.t.u.	95.50	101.60	107.40	103.10	92.90	94.60	99.18	98.3

APPENDIX NO. 3

:RIPTION OF METHODS AND INSTRUMENTS USED IN BTAINING DATA UPON THE PERFORMANCE OF THE GAS LEANING PLANT

Temperatures. The temperature of the gas entering the cleaning plant ısured and automatically recorded by a Bristol pyrometer. Readings of ıs temperature are taken by the operators every three hours, after the eaning plant, after the wet scrubbers, and before and after the Theisen :rs, the last temperature being also recorded by a Bristol recording ther- ıter. Temperature readings are further taken at the inlet and outlet of gas holder. All thermometers have the fahrenheit scale and are perma- y installed in the pipe lines. The water temperatures are read every three at the pump suction, after each wet scrubber and after the Theisen :rs. For the purpose of comparison the temperature of the atmosphere the washer building is simultaneously recorded. Portable thermometers the fahrenheit scale are used for measuring water temperatures.

Pressures. Readings are taken by the operators every three hours, by s of ordinary U-tubes, of the gas pressure in inches of water at the follow- laces: at the point where the gas enters the cleaning plant, between the :rubbers, and before and after the Theisen washers. In addition, the pres- of the raw gas at the main water seal, and of the fine gas after the Theisen ers, is continuously recorded by Bristol pressure gages. For convenience)servation all instruments indicating and recording gas and water pres- ı, temperatures and venturi meter pressure differences, are arranged on a board (Fig. 40) installed in the Theisen washer building. On the same gage- d the telephone gongs and the optical indicators showing the position of two gas-holder bells are mounted. By a simple system of contacts each holder bell, while descending, closes five different electric circuits, and es incandescent lights to burn corresponding to its different positions. s a white light burns when the holder is in its top position; a green light :ars when the holder bell has descended 7 ft.; one red light, indicating danger, esponds to a 14-ft. immersion of the holder bell, and two, and at last three, lamps show that the bell has fallen 21 ft. and 28 ft. respectively, and is ing its bottom position. When the three red lights burn the gas holder is :tically empty. Similar optical indicators are installed in the electric er and gas blowing-engine houses, so that the engine operators can inde- dently observe the position of the gas holders at any time.

Power Consumption. As all Theisen washer and pump motors are oper- l by 440-volts alternating current reduced in special transformers from 2200 , 25 cycle, 3-phase current generated in the electric station, an integrating

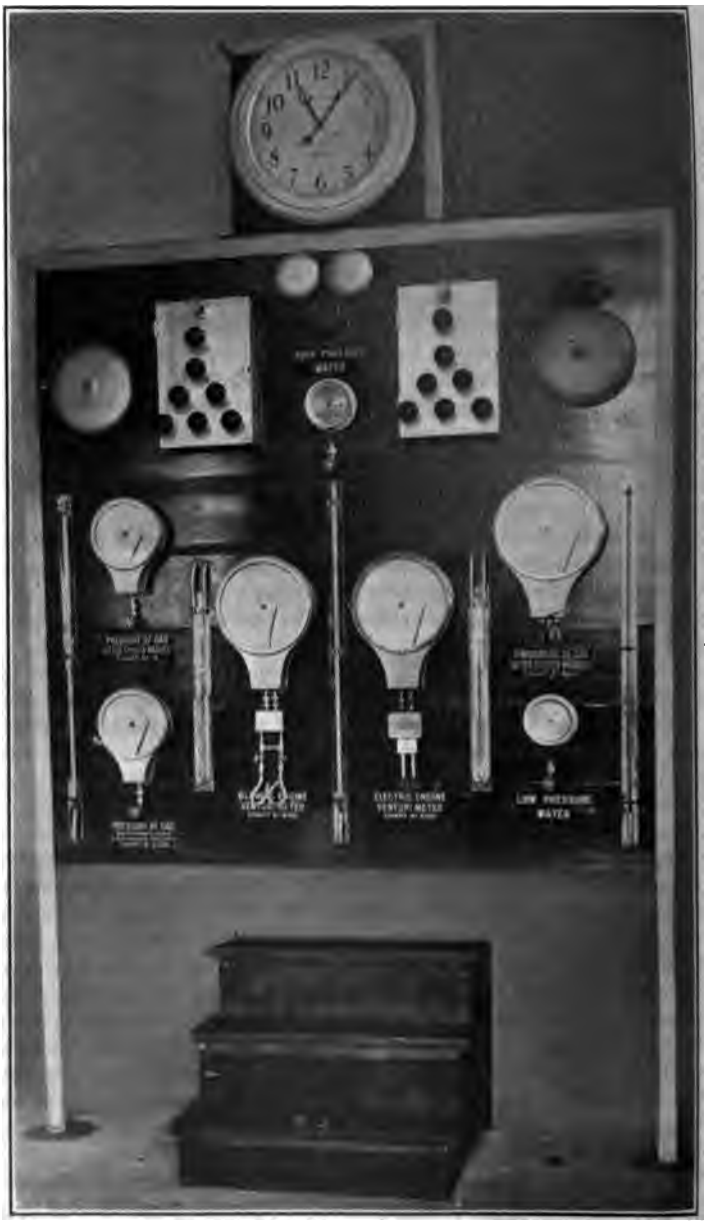


FIG. 40 GAGEBOARD IN THEISEN WASHER BUILDING

kilowatt meter was installed at the main switchboard to measure the combined power consumed by all gas cleaning plant motors. Unfortunately, the motor-driven air compressors for starting the gas engines are on the same line, so that the power for two 50-h.p. motors is included in the meter readings; but since each air compressor is running only about one hour each day, the error is believed to be of little weight. However, it must be kept in mind that on this account the recorded power consumption of pumps and Theisen washers is higher than the actual values. A portable ampere meter for use in the Theisen washer building can easily be attached to each motor and read by the operator every three hours, and the readings are recorded in the daily report sheets. These ampere meter readings give the only indication of the load carried by each Theisen washer. As all washers operate in parallel, one machine, by a slight misadjustment of the inlet and outlet gate valves, may handle more gas, thus carrying more load, and cleaning its share of the gas to a less extent than the other washers. The ampere meter will indicate such an inequality in the load distribution, and the operators have orders to keep the ampere readings on all washers in operation fairly uniform, by proper adjustment of the gate valves. The indications of the ampere meter, averaged for each month, are used to divide the power charges in proper proportion between the pumps in the preliminary washing plant and the Theisen washers.

110 *Water Consumption.* The amount of water consumed each minute in the gas-washing plant is measured by overflow weirs at the settling tank. A hook gage gives directly the number of gallons of water per minute falling over the weir so that the operator reads the water quantity as easily as a thermometer. The settling tank has two compartments, so that the water from the wet scrubbers can be turned into one, while the Theisen waste water is flowing into the other compartment. Gates make it possible to reverse these flows and to shut off each settling tank for cleaning. The amount of water allowed at each wet scrubber and Theisen washer, originally apportioned by means of calibrated barrels, is adjusted in practice by estimating the relative quantity basing the estimate on the thickness of the stream at each Theisen water inlet and at the wet scrubber overflow. The water used for gas-washing purposes is waste cooling water from the blast furnaces, formerly discharged into the sewer but now collected and piped to the Theisen washers under its natural head, while another part is lifted on top of the wet scrubbers by two centrifugal pumps of 2,000,000-gal. capacity each. These pumps receive the water under 30 ft. head and deliver it at a pressure of 80 ft. for distribution through the sprinkler system.

111 *Dust and Moisture.* Gas engine builders usually specify the amounts of dust and moisture which should not be exceeded for safe operation. Recent specifications call for blast furnace gas containing not more than 0.02 grains of flue dust and not over 10 grains of moisture per cu. ft., at 62 deg. fahr. and 30 in. mercury. With an efficient, modern gas-cleaning plant it is not difficult to meet these conditions, as is shown in the paper. Dust and moisture determinations are made in the gas laboratory, and recorded on daily chemical report blanks (Fig. 6). The amount of dust is determined in dry cleaned gas, clean gas and fine gas, and occasionally in the atmosphere, while moisture determinations are made in clean and in fine gas. For purposes of comparison the moisture in the atmosphere, as determined at the dry-blast plant, is also recorded.

Results are given in grains per cu. ft. of standard gas, and by a simple calculation the efficiency of the wet scrubbers and of the secondary washing plant can be determined each day.

112 While frequently tried, it has been found impossible to make dust determinations in raw gas, which give more than a general idea of the efficiency of the dry cleaning plant. The difficulty is that the raw gas frequently carries larger particles of dirt, which obstruct the sample pipe and clog the dust filter before a gas sample of sufficient size for correct determination can be secured.

113 A series of tests extending over eight days was made in August 1906, with the regular dust filter apparatus then in use, but since no results were obtainable, a long glass tube open at both ends and filled with dry calcium chloride was then weighed and attached to the gas main in place of the dust filter. After passing several cubic feet of gas, the glass tube was taken off, closed at both ends and weighed, the difference in weight giving the total amount of dust and moisture. The amount of dust was determined by drying and weighing again as the difference between the second and third weighings. This apparatus was found to be a little more satisfactory, as larger samples could be taken, but gradual filling of the pipe with dust made the accuracy of the results very doubtful. The size of the gas sample secured never exceeded 6 cu. ft., with an average of about 2 cu. ft.

114 Tests made in August 1907 gave similarly unreliable results, as the amount of dust in raw gas, according to these determinations, varied from 0.18 grains per cu. ft. at 2 p.m., August 7, to 563.19 grains per cu. ft. at 4.30 p.m. August 20. Such extreme variations are improbable, and as the results obtained cannot represent a fair average, raw gas dust tests were discontinued as of questionable value.

115 The method and the instrument used for the determination of dust in clean and fine gas were developed by Messrs. Wm. Brady and L. A. Tousalin. The Brady filter (Fig. 41) consists essentially of a brass cylinder provided with inlet and outlet and supporting the filter itself, which is an ordinary 94 x 33 mm. Soxhlet extraction shell. The brass cylinder is of such diameter that an annular space of about $\frac{3}{16}$ in. is formed between its inner surface and the paper filter. The filtering shell is fastened and held tightly in place without the aid of gaskets, by wedging its open end between the tapering cylindrical faces of the brass shell and the brass nozzle, as shown in the illustration. This method of fastening has the additional advantage that for a distance of about one-half an inch from the edge, the Soxhlet shell is protected from dust deposits so that the filter can safely be handled after the experiment. The brass nozzle forming the inlet of the apparatus is provided with inside threads so that it can be screwed to a sampling pipe. Its inside surface is perfectly smooth, without ledges or places for the accumulation of dust. A brass nut holds the three parts of the instrument in place. The apparatus may be used in any position, but the preferred arrangement is horizontal.

116 When the gas to be filtered contains moisture the filtering device must be heated to about 110 deg. cent. by any suitable means, but preferably by surrounding the brass shell with an electrically heated sleeve as shown in Fig. 42, which represents the sampling pipe, Brady filter, moisture tubes and gas meter assembled ready for use. The nipple on the outlet end of the brass cylinder is threaded so that it can be removed and replaced by aluminum

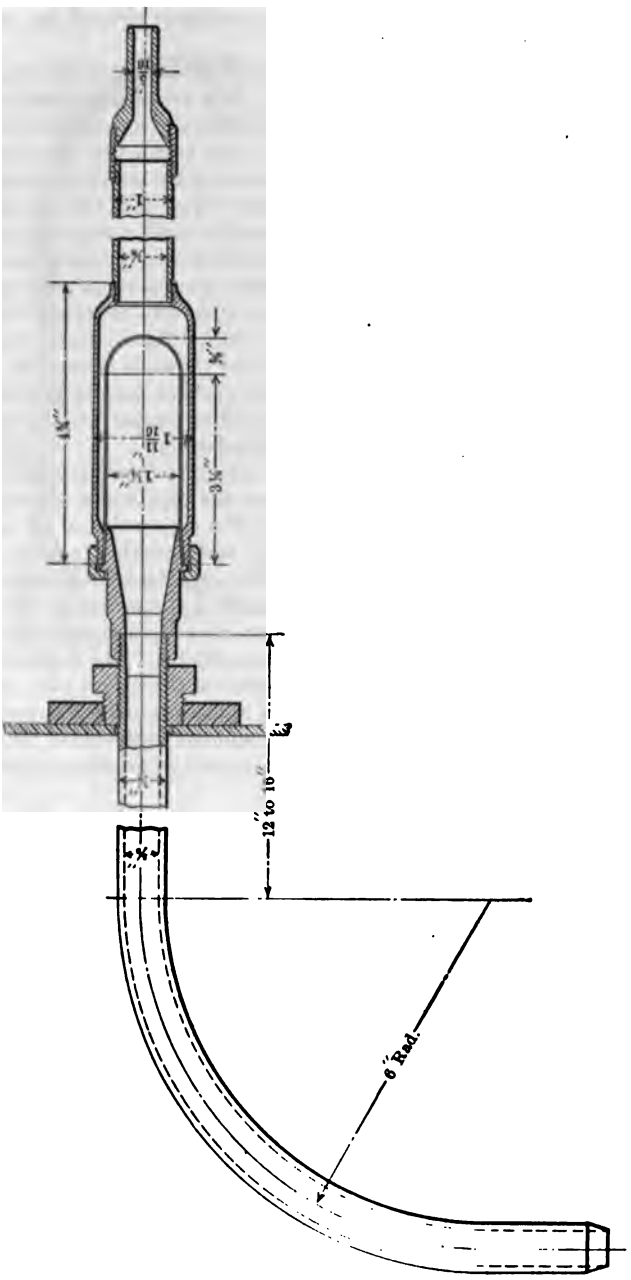


FIG. 41 SECTION OF BRADY DUST FILTER

tubes filled with a dehydrating agent such as calcium chlorid, in case it is desired to determine the moisture in the gas.

117 The Brady dust filter was chosen for use as standard instrument on account of its advantages over other methods. It is very simple, easily assembled and taken apart, perfectly tight, and it fulfills the requirement that the gas issuing from the sample pipe should pass over very little surface before being filtered. The principal advantage, however, is the use of a strong cylindrical filter which resists the gas pressure much better than the thin sheet of filter paper used in other instruments. The Soxhlet shell maintains a porous condition even though much fine dust has been deposited owing to the formation of concentric layers of dust and their subsequent cracking by the action of gravity and slight jarring. Gas samples of twice the size permissible in other instruments can be passed through the Brady filter. Fig. 43 shows five Brady filter shells after use for determination of dust at the main water seal, before and after the wet scrubbers, after the Theisen washers, and after the power station gas holder. The feature of keeping the filter porous for large samples is noticeable, particularly in the shell on the extreme left.

118 Whenever determinations of dust and moisture, or both, are desired, the instrument must be placed as close as possible to the pipe where the sample is to be taken. The sampling pipe used, shown in Fig. 42, consists of a ½-in. brass pipe curved with a radius of not less than 6 in. and smoothly polished on the inside. It is inserted in the gas flue, if possible on a horizontal diameter at least 15 ft. away from any bend or obstruction, to a distance of one-fourth to one-third of the diameter. The inlet opening is reduced to a sharp edge, so that there is as little local disturbance at that point as possible. The question of the proper form of sampling pipe was decided in favor of the curved pipe, against the straight pipe with standard 4-in. insertion in the gas main. Experiments were made at various times to determine the amount of flue dust, by simultaneously using both forms of sampling pipe inserted at practically the same place in the gas flues.

119 A comparison of the results of these tests shows plainly the difference in the effect of straight and curved sampling pipes on the size of the gas sample, which generally speaking is larger with the curved pipe. This advantage is, however, of secondary importance, compared with the material increase in the dust contents recorded by sampling the gas with curved pipes. This increase is particularly noticeable in testing dry cleaned gas, and shows that the heavier particles of dust cannot easily be induced to change their direction of travel to enter the straight sample pipe at right angles, but pass by the opening, which is parallel with the gas stream. The difference in results averages nearly 100 per cent in favor of the curved sampling pipe.

120 In the clean gas tests this difference is considerably less marked and the average size of the gas sample obtained is even smaller, while the amount of dust recorded when using the curved sampling pipe is only 8½ per cent larger, because the dust remaining in clean gas is of much finer quality and of less specific gravity, so that the particles will much more easily change their direction of travel. No difference at all, however, can be observed when dealing with fine gas. The averages of two series of tests coincide exactly, and only slight deviations are noticeable in the individual readings. The average size of the gas sample taken with the curved pipe is 14 per cent larger than the sample

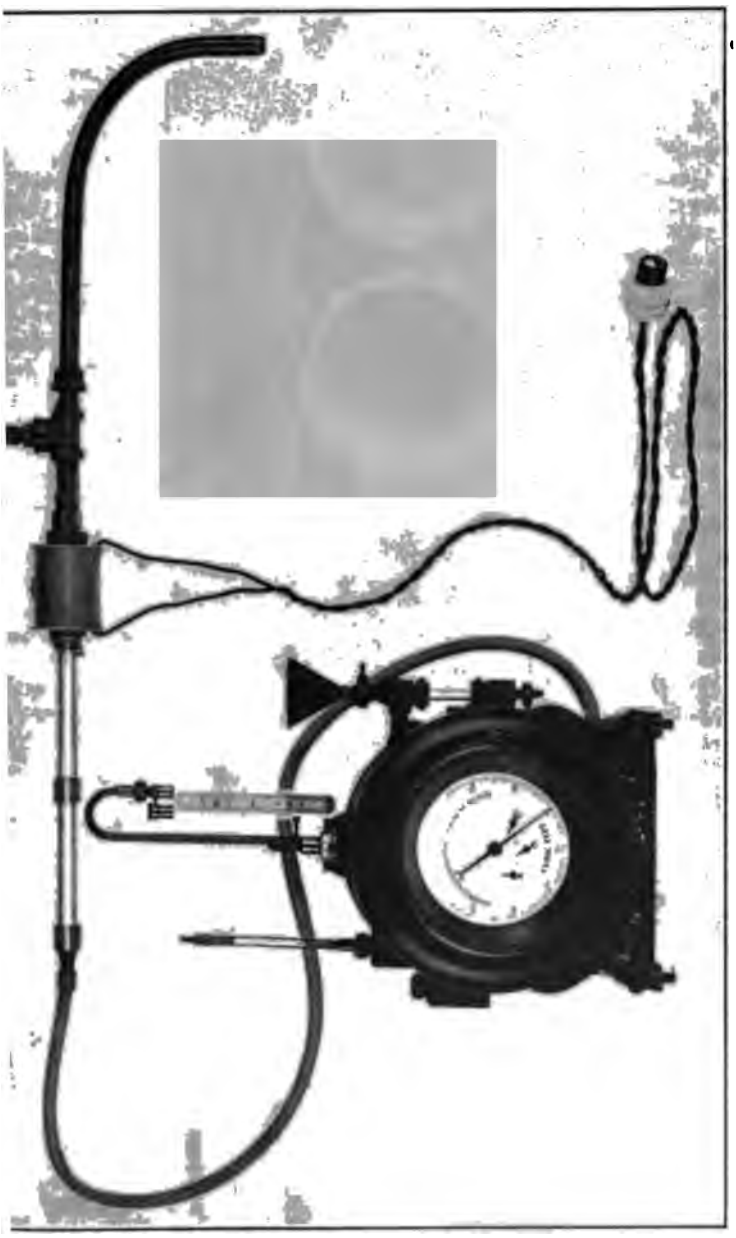


FIG. 42 BRADY FILTER, SAMPLING PIPE AND GAS METER

FIG. 43 BRADY FILTER SHELLS AFTER USE

ned with the straight sampling pipe. This experience is valuable as it
s that dust determinations in fine gas are very much less influenced by
tions in the method of sampling, which further suggests that results will
e materially affected by variations in the instruments and methods used
ust determinations in fine gas.

As the original gas pressure is usually—in fine gas always—sufficient to
) the gas to flow through the filter, an aspiration of the sample is unneces-

The determination is made as follows: The Soxhlet shell is first dried and
hed in a glass weighing bottle, then inserted into the brass shell of the
ratus, and the parts tightly connected. A meter reading is taken after the
ument is connected to the sample pipe and the gas is turned on. The dust
ained in the gas sample is deposited in the Soxhlet shell, while the moisture
iven over into the aluminum tubes containing anhydrous calcium chlorid,
connected in series. They are capped and weighed before the experiment
their increase in weight represents the moisture in the volume of gas passed
ugh the apparatus, while the increase in weight of the shell after drying gives
amount of dust carried in the gas sample. For dust determinations from
) over 200 cu.ft. of gas are passed, depending on conditions of pressure
locality, while for moisture determinations only from one to five cu. ft.
used. Usually one or several moisture tests may be made while one dust
is being run, simply turning off the gas for a moment when the aluminum
es are inserted and again when they are withdrawn. Readings of the meter
of the gas conditions such as temperature and pressure must of course be
le at the beginning and end of each test. All results of dust and moisture
s are calculated to grains per cu. ft. of standard gas.

2 The application of two Brady filters permits continuous determination,
ature of great importance in gas power plants since it permits uninterrupted
'eillance of the gas cleaning plant and of its efficiency. Continuous dust
rminations are being made every day except Sunday, by sampling dry
ned gas, clean gas and engine gas. A Brady filter is started at each place
.30 a.m., and the gas is allowed to pass until 4.30 p.m., when the Soxhlet
l is removed and a new one inserted, which is in continuous use from 5.00
. until 8.00 a.m. the following morning. The average size of sample for
and night runs respectively, is from 60 to 90 cu.ft. of dry cleaned gas,
o 160 cu.ft. of clean gas, and 120 to 200 cu.ft. of engine gas. It is evident
t such large accumulative samples must very nearly represent a true aver-
of the amount of dust contained in the gas. Occasional dust and moisture
erminations usually practiced in the majority of plants are of compara-
ly little value, as they do not give the true average conditions of the gas.
nparisons of results obtained at different gas-cleaning plants cannot and
uld not be made and credited, unless all instruments, methods, size of sam-
, duration of tests, etc., are identically the same. Standardization of the
hod of determining dust and moisture in industrial gases would benefit
gas engine industry at large, and the method used at this plant, which has
n thoroughly and continuously tried under all conditions, is worthy of con-
eration as a basis for standardization

TABLE 12 GAS AND WATER TEMPERATURES

MONTHLY AVERAGES

1909	Jan.	Feb.	March	April	May	June	Avg. Jan.-June
Temperature of gas to wet scrubber No. 1, deg. fahr.	123.20	126.00	161.00	152.00	163.20	173.00	149.90
Temperature of gas to Theisen washers, deg. fahr.	41.40	44.00	49.60	55.50	63.80	74.20	54.70
Temperature of gas to gas holder, deg. fahr.	40.10	43.00	44.10	52.50	64.20	69.70	52.30
Temperature of water supply, deg. fahr.	43.80	45.00	44.20	52.30	62.80	71.70	53.30
Waste, wet scrubber No. 1, deg. fahr.	59.20	63.00	62.50	67.20	77.00	84.80	68.90
Waste, wet scrubber No. 2, deg. fahr.	43.30	44.00	46.80	52.70	63.20	72.90	53.30
Temperature of air, deg. fahr.	27.90	31.00	37.10	46.40	56.90	65.10	44.10

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Avg. July-Dec.	Av Jan De
Temperature of gas to wet scrubber No. 1, deg. fahr.	169.20	173.60	150.60	159.50	119.30	86.70	143.30	146
Temperature of gas to Theisen washers, deg. fahr.	76.50	79.10	72.70	61.80	61.70	52.80	67.40	61
Temperature of gas to gas holder, deg. fahr.	79.10	80.90	72.30	61.00	61.10	42.00	54.40	53
Temperature of water supply, deg. fahr.	74.70	78.60	72.80	63.70	64.50	46.20	66.70	60
Waste, wet scrubber No. 1, deg. fahr.	89.00	96.70	95.50	94.70	92.50	88.80	92.80	90
Waste, wet scrubber No. 2, deg. fahr.	76.70	81.50	77.10	64.90	65.40	52.70	67.70	61
Temperature of air, deg. fahr.	83.40	85.20	74.60	60.80	58.80	31.20	65.00	54

TABLE 13 EFFICIENCY OF SECONDARY WASHING PLANT

MONTHLY AVERAGES

1909	Jan.	Feb.	March	April	May	June	Avg. Jan.-June
Flue dust in clean gas, grains per cu. ft.	0.0766	0.1224	0.2238	0.2178	0.2146	0.2330	0.1980
Flue dust in fine gas, grains per cu. ft.	0.0036	0.0057	0.0044	0.0059	0.0067	0.0067	0.0055
Difference	0.0730	0.1167	0.2194	0.2119	0.2079	0.2322	0.1770
Per cent removed by refining	95.4	95.4	98.0	97.4	96.6	97.3	97.6

APPENDIX NO. 4

IN DETAIL OF OPERATION OF GAS-CLEANING PLANT

TABLE 10 HEAT LOSS OF GAS BY RADIATION

MONTHLY AVERAGES

08	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average
u. ft. per min.	14,020	12,850	16,950	18,070	17,690	13,090	15,420
f gas at main deg. fahr....	426	410	303	312	299	329	346
f gas to scrub- leg. fahr.....	210	196	202	168	150	133	177
diation, deg.	216	214	101	144	149	196	169
n per cent...	50.7	52.2	33.3	46.1	49.8	59.5	48.8

TABLE 11 WET SCRUBBER EFFICIENCY

MONTHLY AVERAGES

1909	Jan.	Feb.	March	April	May	June	Avg. Jan.-June
dry-cleaned gas, cu. ft.....	0.4772	0.4787	1.2951	1.0335	0.2146	1.0804	0.9137
lean gas, grains per	0.0766	0.1224	0.2238	0.2178	1.1172	0.2389	0.1825
.....	0.4006	0.3563	1.0713	0.8157	0.9026	0.8415	0.7312
ed by wet scrubbers	84.0	74.5	82.8	79.0	80.8	77.8	79.7

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Avg. July-Dec.	Avg. Jan.-Dec.
dry cleaned gas, gr.	0.7990	1.6124	4.0940	2.8794	2.4004	1.1188	2.1506	1.5330
lean gas, gr. per cu.	0.1316	0.3669	0.8257	0.9882	0.2539	0.1786	0.4541	0.3183
.....	0.6674	1.2455	3.2683	1.8912	2.1465	0.9402	1.6965	1.2147
oved by wet scrub-	83.5	77.4	79.9	65.7	89.6	84.2	78.8	79.3

TABLE 13—CONTINUED.

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Avg. July-Dec.	Avg. Jan.-Dec.
Flue dust in clean gas, grains per cu. ft.	0.1316	0.3669	0.8257	0.9882	0.2539	0.1786	0.4541	0.[illegible]
Flue dust in fine gas, grains per cu. ft.	0.0057	0.0058	0.0080	0.0074	0.0069	0.0093	0.0061	0.[illegible]
Difference	0.1259	0.3611	0.8177	0.9808	0.2470	0.1693	0.4480	0.[illegible]
Per cent removed by refining	95.6	98.5	99.0	99.1	97.5	95.0	98.7	98.1

TABLE 14 DETERMINATION OF FLUE DUST AT DIFFERENT POINTS OF SECONDARY CLEANING PLANT

GRAINS PER CUBIC FOOT

1910	Turn	After wet scrubbers	Before Theisen washers	After Theisen washers	After gas holder
March 21	night	0.1496	0.1091	0.0024	0.[illegible]
March 22	day	0.1681	0.1468	0.0066	0.[illegible]
March 22	night	0.1647	0.1292	0.0045	0.[illegible]
March 23	day	0.1773	0.1563	0.0091	0.[illegible]
March 23	night	0.1185	0.1145	0.0062	0.[illegible]
March 24	day	0.1566	0.1480	0.0058	0.[illegible]
March 24	night	0.1456	0.1371	0.0066	0.[illegible]
March 25	day	0.1568	0.0963	0.0067	0.[illegible]
March 25	night	0.1474	0.1258	0.0064	0.[illegible]
March 26	day	0.1425	0.1078	0.0037	0.[illegible]
Average		0.1527	0.1274	0.0058	0.[illegible]

Average amount removed

By clean gas main ..... 0.0253 grains per cu. ft.
By Theisen washers ..... 0.1216 grains per cu. ft.
By fine gas main and gas holder ..... 0.00035 grains per cu. ft.

Average absolute efficiency of

Clean gas main ..... 16.56 per cent
Theisen washers ..... 95.45 per cent
Fine gas main and holder ..... 6.03 per cent

The average total efficiency of the secondary cleaning plant was 98.43 per cent, in which the three above factors participated as follows:

Clean gas main ..... 16.56 per cent
Theisen washers ..... 79.64 per cent
Fine gas main and gas holder ..... 0.23 per cent

Total ..... 96.43 per cent

TABLE 15 DUST IN COMBUSTION AIR

DAY TURN						NIGHT TURN				
Wind	Temp. of air deg. Fahr.	Barometer	No. cu. ft. sample	Dirt grams per cu. ft.	Weather	Temp. of air	Barometer	No. cu. ft. sample	Dirt grains per cu. ft.	
W.	78	29.21	74.13	0.0052	Part Cloudy	70	29.31	81.85	0.0043	
W.	76	29.19	95.57	0.0032	Part Cloudy	71	29.26	57.50	0.0037	
S. W.	80	29.27	124.51	0.0013	Wind blowing hard	73	29.28	102.84	0.0053	
W.	84	29.28	126.41	0.0048	Part cloudy	76	29.28	129.11	0.0036	
N. W.	80	29.34	88.69	0.0004	Wind hard	86	29.40	95.46	0.0005	
N. W.	84	29.39	145.82	0.0004	Clear	..	.....	.....	.....	
.....	.....	.....	109.19	0.00255	.....	.....	.....	93.37	0.00346	

ANALYSES OF DUST DEPOSIT ON GAS AND AIR DAMPERS OF GAS ENGINE NO. 1

ample February 1909	Gas Damper		Air Damper	
	1	2	3	4
.....	19.60%	22.50%	32.40%	23.80%
.....	12.07	20.19	6.50	11.30
.....	6.95	6.37	11.12	12.03
.....	2.52	2.62	1.04	1.15
.....	32.74	23.00	5.84	5.37
.....	3.43	3.38	0.92	0.95
.....	17.89	17.38	37.84	39.85

ANALYSES OF FLUE DUST REMOVED FROM BLAST FURNACE GAS AT DIFFERENT STAGES OF GAS CLEANING

March 1908	SiO_2	Al_2O_3	Fe	CaO	MgO	Fix C.	Sul.	Phos.	Mang.	Vol.
water seal (deposit).....	10.30	4.60	48.85	2.46	0.30	15.52	....	0.067	0.53	....
ecting main after dry plant (deposit).....	11.44	4.45	42.86	3.15	0.68	10.28	0.202	0.079	0.80	7.28
, wet scrubber (sediment)	14.58	5.45	43.09	2.75	0.78	9.17	0.288	0.096	0.60	4.17
2, wet scrubber (sediment)	18.26	5.85	38.20	4.74	1.40	8.54	0.192	0.097	0.47	5.08
ben washers (sediment)	22.93	7.94	26.06	7.60	1.61	11.47	0.314	0.119	1.08	6.73

TABLE 18 ANALYSES OF FLUE DUST REMAINING IN BLAST FURNACE GAS AT DIFFERENT STAGES OF GAS CLEANING

MARCH 1910

Location of Brady filters	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Ma.	W
At main water seal	12.19%	5.93%	52.39%	4.70%	0.97%	1.10%	21
Gas entering wet scrubber No. 1	11.37	5.21	52.55	3.76	0.86	0.88	21
In clean gas main	21.14	11.53	28.35	9.56	1.94	2.46	21

TESTS ON WET SCRUBBERS

123 Tests were made on October 27, 1908, to determine the cooling and condensing effect of the wet scrubbers. The temperatures of the water and entering and leaving the washers were taken with accurate thermometer

TABLE 19 WET-SCRUBBER TEST

	TEMPERATURES							QUANTITIES	
	WATER				GAS			GAS	WATER
TIME	SCRUBBERS				SCRUBBERS				GAL. PER
	INLET 1 and 2	OUTLET 1	OUTLET 2	OUTLET 1 and 2	INLET 1	OUTLET 1	OUTLET 2	CU. FT. PER MIN.	NO. 1 NO. 2
10.50	63.0	80.0	64.0	73.0	157.0	62.8	60.0	17,000	.....
11.00	62.8	77.5	63.0	71.5	156.0	62.8	60.0	17,150	.....
11.10	63.0	77.5	63.2	72.0	156.0	62.8	60.0	17,350	.....
11.20	63.0	76.5	63.5	71.5	155.0	62.8	60.0	17,150	.....
11.30	62.8	77.2	63.0	71.5	155.0	62.8	60.0	17,150	.....
Average....	62.9	77.74	63.34	71.9	155.8	62.8	60.0	17,160	818
2.55	63.6	85.5	63.0	77.0	180.0	64.8	62.0	23,100	.....
3.05	63.8	85.5	63.0	76.5	177.0	64.8	62.0	23,400	.....
3.15	63.8	85.5	63.0	76.0	175.0	64.8	61.5	23,100	.....
3.25	63.5	85.0	63.0	76.5	175.0	64.3	61.5	23,250	.....
3.35	63.5	87.0	63.2	77.0	176.0	64.3	61.5	23,100	.....
Average....	63.64	85.7	63.04	76.6	176.6	64.5	61.7	23,190	782

otal amount of water from both washers was measured by the weir, and the nts passing through each washer were calculated from the final temper- s. The gas was measured by venturi meter. The temperature of the sphere was 45 deg. fahr. Two tests of 40 minutes each were made on the day. The readings and averages are given in the table.

The total heat absorbed in the first scrubber during the first test was 12 B.t.u. per min., of which 31,205 B.t.u. is accounted for in the loss of ble heat in the gas. On the second test the total heat absorbed was 137,874 .per min., of which 50,848 B.t.u. is accounted for by the loss of sensible

From the following calculations the amount of vapor condensed per cu. gas at64 deg. was found to be 27.4 grains in the first, and 25.2 grains in econd test, or an average of 26.3 grains.

st Test:

Washer 1, temperature of entering gas, 155.8 deg.; leaving gas, 62.8 deg.

Density of gas = 0.0815

Specific heat = 0.24

Cu ft. of gas per min. = 17.160

Sensible heat lost by gas:

17,160 × 0.0815 × 0.24 × (155.8 − 62.8) = 31,205 B.t.u. per min.

Heat absorbed by water:

816 × 8½ × (77.74 − 62.90) = 100,912 B.t.u. per min.

100,912 B.t.u. − 31,205 B.t.u. = 69,707 B.t.u.

Average latent heat of vapor from 155.8 deg. to 62.8 = 1037 B.t.u.

$$\frac{69.707}{17,160 \times 1037} = 0.00392 \text{ lb. or } 27.4 \text{ grains of vapor condensed per cu. ft. of gas at 64 deg.}$$

econd Test:

Sensible heat lost by gas:

23,190 × 0.0815 × 0.24 × 112.1 = 50,848 B.t.u.

Heat absorbed by water:

752 × 8½ × 22.06 = 137,874 B.t.u.

173,874 B.t.u. − 50,848 B.t.u. = 87,026 B.t.u.

Average latent heat from 176.6 to 64.5 deg. = 1029 B.t.u.

$$\frac{87,026}{23,190 \times 1029.7} = 0.003605 \text{ lb. or } 25.2 \text{ grains vapor condensed per cu. ft. gas at 64 deg.}$$

25 Since the average temperature of the gas leaving the first scrubber was out 64 deg., the amount of moisture remaining in the gas was about 6.6 grains; s added to 26.3 grains condensed gives 32.9 total grains of moisture per cu. in dry cleaned gas. This represents a dewpoint of about 117 deg. or about per cent saturation at the average initial temperature of 166 deg. Later ts with wet and dry bulb thermometers in the gas mains showed dewpoints rying from 104 deg. to 114 deg. for an average gas temperature of 170 deg. e results of these tests indicate the reducing effect which the washing of gas has on the moisture. While by these calculations the amount of mois- e in the dry cleaned gas was found to be about 33 grains per cu. ft. in October 8, moisture determinations with Brady filters made on July 14, 15 and 16, 9, gave very similar results. It will be noted that the test figures fairly incide with the calculated values.

TABLE 20 MOISTURE TEST IN DRY-CLEANED GAS

Date	CO_2	CO	H	CH_4	B. t. u	$\frac{CO}{CO_2}$
July 14 Gas analysis	14.8	25.5	3.0	0.1	91.8	1.72
Grains of moisture per cu. ft.						34.124
Temperature at meter, deg. fahr.						84
Barometer, inches of mercury						29.27
Temperature in gas main, deg. fahr.						102
Pressure in gas main, inches of water						9.5
July 15 Gas analysis	13.8	25.7	4.0	0.1	95.3	1.86
Grains of moisture per cu. ft.						41.7453
Temperature at meter, deg fahr.						85
Barometer, inches of mercury						29.68
Temperature in gas main, deg. fahr.						156
Pressure in gas main, inches of water						6.5
July 16 Gas analysis	13.1	26.1	3.5	0.2	96.1	1.99
Grains of moisture per cu. ft.						38.421
Temperature at meter, deg. fahr.						83
Barometer, inches of mercury						29.36
Temperature in gas main, deg. fahr.						100
Pressure in gas main, inches of water						10
Average moisture, gr. per cu. ft.						30.1

APPENDIX NO. 5

USED FOR MEASURING AND RECORDING GAS CONSUMPTION

following description of the method used for measuring and record-
onsumption was contributed by C. J. Bacon, Mem. Am. Soc. M. E.
amount of gas consumed by the blowing engines at the blast furnaces
ver engines in the electric station, is measured by venturi meters,
4-in. main to the blowing engines and another in the 60-in. main to
ngines. The 60-in. meter was installed first and tested by volumet-
nents as hereinafter described. The 54-in. meter was subsequently
with the same proportions, and as the only difference is in the size
ve been thought necessary. These meters are of much the usual
t that certain liberties were taken in the design to simplify the shop
hroat section of each being a straight cylinder connected to the
of the upstream and downstream cones without rounding at the in-
and there was a similar omission of curvature at the connection be-
pproach section of 5-ft. pipe and the large end of the upstream cone.
was realized that these departures from theoretically perfect de-
kely to introduce more or less error due to eddy currents, neverthe-
of the facility with which the accuracy could be determined by
ıe gas holder, the somewhat irregular construction was allowed to
absence of test data on meters of this size made tests advisable
f how nearly perfect the shape and construction might be.

eferring to Fig. 23*b* of the paper, it will be seen that the 60-in. meter
-all length of 53 ft. 1 in., and consists of an upstream cone 11 ft. 6
having openings 60 in. and 20 in. in diameter, a straight cylin-
t section of cast iron 20 in. in diameter by 15 in. long, and a down-
39 ft. long, likewise with openings 60 in. and 20 in. in diameter.
am cones are made of plate, with butt-joints and countersunk
to reduce friction. A cylindrical casting 16 in. long by 60 in. in
d containing an annular pressure chamber, is inserted between the
proach pipe and the upstream cone. A similar pressure chamber
he throat. Twelve 3/16-in. holes communicate to each of the
ıe pressures existing within the meter at those points. The char-
ıuation for flow of gas in venturi tubes[1] was used in the calibration
r.

nber of carefully conducted tests have been made at various times to
he meter coefficient, utilizing the 100,000 cu. ft. gas holder as a
olumetric measurement. This holder is located about 260 ft. from

w of Fluids in a Venturi Tube, by E. P. Coleman, Transactions, vol. 28, 1907,
lerivation of this equation.

the meter, and is provided with a combination of water-sealed valves such that the flow of gas to and from the holder may be controlled at will. The horizontal area of the holder was accurately determined by measurement of diameter, and a vertical scale of feet and tenths was marked on the outside to permit of determination of the rate of rise of the holder. Observations were taken of

A gas pressure in the upstream chamber
B difference in pressure between upstream and throat chambers
C temperature of gas at meter and holder
D analysis of gas including water vapor contents
E barometric pressure
F gas pressure at inlet to holder

From these data and the dimensions of the meter, values may be assigned in the above-mentioned equation of flow. It is worthy of especial note that the ratio of specific heats for the mixture of gas and aqueous vapor is in this case 1.38, the use of it in the formulae, however, does not result in an appreciably lesser flow than the use of 1.408, the commonly accepted value for air. Without burdening this paper with the actual data and computations, the net average results of 17 separate holder tests at various rates of flow show a meter coefficient of 0.91, which is taken to mean that the actual flow is 91 per cent of the theoretical flow.

130 This determination of meter coefficient was made more as a matter of scientific interest than as a necessity, since working curves showing the relation between the difference in upstream and throat pressure and volume of gas at prevailing temperatures and pressures, could have been constructed from test data alone. The meter coefficient, however, being available, it was made use of in connection with the theoretical formula in preparing the curves in Fig. 35 of the paper, from which the volume of gas, reduced to standard conditions of 62 deg. fahr. and 29.92 in. barometer, may be determined for prevailing temperatures and meter readings. For these curves the absolute pressure of gas in the main is taken as 29.5 in. mercury, which is the sum of the average upstream pressure and the average barometer at this locality.

131 Daily records of flow of gas are obtained by means of a Bristol differential pressure recorder, located in the Theisen washer building about 250 ft. away from the meter and connected to upstream and throat chambers by two lines of pipe. Comparison of readings at the meter with the recorder shows no error due to the long connecting pipes. The curves of Fig. 35 are used in conjunction with these daily meter charts to obtain the average rate of flow for each day, which with the calorific value, the kilowatt output of the generators and the generator efficiency, gives the data required for computing the daily average thermal efficiency at the engine shaft. The chart shown in Fig. 36 represents a flow of 22.044 cu. ft. per min. Other observations and computations for that day were as follows:

B.t.u. per cu. ft. at 62 deg. fahr.	87.1
Average load, kw.	7306
B.t.u. per kw-hr	15,761
B.t.u. per b.h.p-hr. at 96 % generator efficiency	11,311
Thermal efficiency at shaft	22.5

The monthly averages of these daily data, and the results for the year 1909 are shown in Fig. 38.

132 Questions are often raised regarding the amount of dust deposited in meters for blast furnace gas. The 60-in. meter has been examined at six-month intervals. The first inspection showed a slight accumulation of moist dust at and near the throat, but not in sufficient quantity to affect the results appreciably; at the second examination no dirt was found; at the third a considerable coating of dirt was found and was cleaned out, unfortunately without accurate measurement of the average thickness. As a means of determining the effect of the reducing diameter on the flow of gas, a comparison was made of the average thermal efficiency for a week preceding and a week following the cleaning as follows:

Week preceding cleaning	16.9 per cent
Week following cleaning	19.0 per cent
Reduction of flow	11 per cent

As far as known no change occurred at the engines to affect the efficiency; consequently, since the flow through the meter varies directly as the area, the reduced diameter due to dust was $\left(\frac{16.9}{19.0}\right)^{\frac{1}{2}} \times 20$ in. = 18.8 in. Therefore the average thickness of the coating was approximately 0.6 in.

133 The cause of this unusual deposit is ascribed to one of the furnaces making special irons, ferrosilicon and spiegel, during the latter part of August and the entire months of September and October 1909, or about 68 days during which the amount of dust found in the raw gas was excessive, as explained in Par.73 of the paper. On this basis it is assumed that the deposit began late in August and continued at a uniform rate through October, when the error amounted to a maximum of 11%. Suitable corrections were made on the monthly averages shown in the tables and charts. To prevent a repetition of the accumulations of dust in the venturi meter a system of spray nozzles (shown in Fig. 23*b*) was installed, for flushing the meter throat thoroughly with high-pressure water.

APPENDIX NO. 6

SUMMARY OF OPERATING RESULTS DURING THE FIRST FOUR MONTHS OF 1910

134 In January 1910, the first gas blowing engine was started very successfully, and since that time two more have been put in operation, furnishing blast to three furnaces. One of these engines is blowing blast furnace No. 4 without the aid of steam blowing engines, delivering 40,000 cu. ft. of air per min.

135 The change in the arrangement of the preliminary gas cleaning plant mentioned in the paper was put into effect in January and the results obtained by operating four wet scrubbers in parallel are very satisfactory.

136 The addition of gas blowing-engines and the larger output of the gas-electric station has very materially increased the quantity of power gas consumed, so that at present about 27,500 cu. ft. of gas are being purified each minute with four gas-electric and three gas blowing-engines in operation. The average quantity of gas cleaned per minute for the first four months of 1910 was 20,845 cu. ft. or about 25% more than the average for the year 1909 and 46% more than the corresponding average from January to April 1909.

137 Inasmuch as five blast furnaces have been in operation since the beginning of the year, and since gas blowing-engines are supplying a large percentage of the blast to these furnaces, the gas supply has always been more than sufficient, the surplus gas being utilized at present to fire the boilers at the adjacent plate mill, which heretofore had been fired with coal.

138 The average output of the gas power plant for the first four months of 1910 was 5663 kw., corresponding to a load factor of 70.8%. The average time of operation of the plant for this period was 557 hours per month or 77.5% of the total possible time. Repairs on the engines were responsible for 17.5%, while operation of the plant caused 5% of the shutdowns. In no instance was lack of gas responsible for time lost during this period. The gas pressure of the raw blast furnace gas averaged 10.6 in. of water, while the average gas pressure after the secondary washers was 14.9 in.

139 Under present conditions, with blast furnace No. 1 out of blast and the plate mill boiler house receiving gas, the bulk of the gas for the engines is being furnished by furnace No. 3. This was most strikingly proved a few weeks ago, when for certain operating reasons the watering of the stock on this furnace was abandoned. The consequence was a tremendous increase in the amount of flue dust carried into the gas cleaning plant, which became so serious that the watering of the stock on this furnace had to be resumed. Since furnace operation during this period was remarkably smooth and uniform no difficulties or troubles were encountered in the operation of the gas engines from back-firing and premature explosions, nor did sudden changes in the quality of the gas occur.

140 The average composition of the blast furnace gas delivered to the engines or the first four months of 1910 was 14.8% CO_2, 25% CO, 3.59% H and 0.22% CH_4, with a computed heat value of 93.15 B.t.u. and a heat value of 92.9 B.t.u. per cu. ft. determined by calorimeter. The ratio $\frac{CO}{CO_2}$ was 1.69, materially lower than for the corresponding period of 1909. when it was 2.1, indicating low coke consumption and a more rational operation of the furnaces.

141 The average temperature of the gas entering the gas cleaning plant was 155 deg. and 84 deg. before the wet scrubbers. The reduction in temperature due to radiation through the unlined zigzag flue was therefore 67% in 1910 against 66.6% for the corresponding period of 1909, the average air temperature being 40 deg.

142 Since the velocity of the gas traveling through the pipes is materially greater on account of the larger quantity of gas purified, only small quantities of flue dust are being deposited in the dust legs of the zigzag flue and the gas delivered to the wet scrubbing plant is considerably dirtier than it was last year. The amount of flue dust in dry cleaned gas averaged 1.8061 grains per cu. ft. with a minimum of 1.3979 grains in January and a maximum of 2.3361 grains in April. The wet scrubbers, only two of which were operating in series up to May 1910, removed from the gas an average of 91.5% of the flue dust, delivering clean gas containing an average of 0.1488 grains per cu. ft. This high efficiency of the wet scrubbers is maintained with four scrubbers operating in parallel. With over 27,000 cu. ft. of gas cleaned per minute, the four wet scrubbers have removed in May 1910, an average of 96.1% of the impurities received. The average temperature of the clean gas delivered to the Theisen washers was 52 deg., the gas entering the gas holder at 50.55 deg. These temperatures were lower than the temperature of the water supply, 55.41 deg., since the average air temperature did not exceed 40 deg. for the first four months of the current year. The temperature of the waste water from the first wet scrubber was 86.85 deg. on account of the larger quantity of gas passing per minute, and the temperature of the waste water from the second scrubber, 56.38 deg., was only a little higher than the temperature of the water supply, proving that the cooling effect took place almost exclusively in the first wet scrubber.

143 The amount of moisture in the clean gas was 4.735 grains per cu. ft. and the fine gas carried 3.658 grains against 1.994 grains of moisture in the atmospheric air. The larger amount of moisture in 1910 is due to the reduced water consumption and to the larger quantity of gas purified per minute, which reduced the time during which the cooling and condensing effect of the water and the atmosphere acted on the gas.

144 The efficiency of the secondary cleaning plant was over 96%, with a minimum of 95% and a maximum of 97% in January and April respectively. The amount of flue dust in the fine gas averaged 0.00632 grains per cu. ft., being 9% higher than the average for the whole year of 1909, while the amount of gas cleaned per minute was 25% larger. It is to be noted that the overall efficiency of the wet scrubbing and secondary cleaning plants for this period was 99.6%, so that only 0.4% of the amount of dust originally contained in the dry cleaned gas was carried over into the gas engines.

145 The quantity of water used in the Theisen washers averaged 17.5 gal. per 1000 cu. ft. of gas cleaned or about two gallons less than the average for the

whole year of 1909. A marked economy in the amount of water used in the wet scrubbers was realized, only 63.1 gal. of water being supplied per 1000 cu. ft. of gas cleaned. The reduction in the total water consumption amounted therefore to more than 20% compared with 1909, and a further reduction is being tried at present, since it was found that with four wet scrubbers operating in parallel the clean gas is relatively cleaner than it was with series washing in two wet scrubbers.

146 Unfortunately the power consumption, and therefore the cost of cleaning per unit of gas will not be very much affected by such a reduction, since the wet scrubber pumps do not use more than about 10% of the total amount of power consumed in the gas cleaning plant.

147 The average power consumption for the first four months of 1910 was 0.308% for the wet scrubber pumps, 3.011% for the Theisen washers, the total being 3.319% of the combined output of all gas engines.

148 The heat consumption of the gas-electric station with an average load of 91.45% on the engines while in operation was 16,873 B.t.u. per kw-hr. or, at 96.2% generator efficiency, 12,101 B.t.u. per b.h.p-hr., so that the average thermal efficiency at the shaft for the first four months was 21.1%. The averages for the individual months were 20.9%, 21.9%, 20.8% and 20.8% respectively.

149 While it has not yet been possible to determine the thermal efficiency of the various types of gas blowing engines recently installed, Venturi meter measurements of the total quantity of gas delivered to the gas holder indicate that the heat consumption of the three engines operating at about 70% of their full load capacity averages about 12,000 B.t.u. per b.h.p-hr., these engines operating at about 70% of their full load capacity. The thermal efficiency of the plant is therefore about 21%. The result of the fuel economy of the gas-blowing engines is a very marked reduction in coal consumption of the plants which are directly or indirectly benefited by the installation of these engines.

DISCUSSION

A. E. MACCOUN.[1] Mr. Freyn's statement regarding the excess power from blast furnaces is, I think, a little excessive. Where blast furnace plants are connected with steel works, requiring all their excess power, or are in such locations that they can dispose of their surplus power at a profit, there should be no hesitancy in installing gas engines for at least 85 per cent of the power required in blowing the furnaces and for generating electricity for use at the works or for transmission. But in cases where blast furnaces are not so ideally located gas engine installations cannot be recommended in preference to steam on account of the higher cost of the former. All conditions of this kind should be carefully studied, as in many cases gas-engine installations may be carried too far.

[1] Superintendent of Furnaces, Carnegie Steel Company, Braddock, Pa.

I fully agree with Mr. Freyn in not trusting to automatic arrangements for regulating the gas supply, as the gas pressure must necessarily be kept up in any gas system to insure safety. If the gas pressure falls below that of the atmosphere and air enters, there is always great danger of a very serious explosion.

We have noticed practically the same condition Mr. Freyn refers to in regard to getting, at times, a supply of ferro-silicon gas, spiegel gas, or ferro-manganese gas at the gas engine in case a furnace making one of these products happens to have its gas entering the main in the vicinity of the gas-washer intake. At the Edgar Thomson plant there are eleven furnaces connected to one gas main, but the different gases seem to equalize themselves in the main according to their pressures, and the quality of gas depends on where it is taken from the main.

In all blast-furnace gas-engine plants there has been more or less experience with back-firing, especially when making special grades of iron, such as ferro-silicon, spiegel, etc. The inlet valves of the engine should be designed so that where this occurs for long periods, endangering operations, the relative areas of the gas and air ports can be changed quickly by hand while the engine is in operation between the limits of 1 unit of air to 4 of gas, and vice versa.

The discrepancies in the heat values are accounted for by the fact that analyses are made about every three hours, while calorimeter readings are taken almost continuously. Some time ago we had occasion to make an average of 168 gas analyses during one of our tests on a furnace running on 1927 lb. of coke per ton of iron. The results were: CO_2 = 16.33 per cent, CO = 22.73 per cent, H = .99 per cent, CH_4 = 0.04 per cent, N = 58.91 per cent. The calculated heat value per cu. ft. of this gas at 62 deg. fahr. and 30 in. mercury was 80.55 B.t.u. From approximately the same number of Junkers calorimeter readings taken at the same time the result was 75.84 B.t.u. per cu. ft. The gas from a blast furnace frequently contains over 24 grains of moisture per cu. ft. When the analyses are made it is customary to get the percentage of the different constituents by volume, excepting the moisture it contains. When the gas is cooled before making the determinations, a large percentage of the moisture is condensed, and by not making allowance for this moisture the gas is figured as of slightly higher thermal value than it actually is. The thermal readings from the calorimeter are usually considered more accurate than those figured from analyses.

All of the gas-washing plants for gas engines that have been

installed in this country have been very successful, so far as I know, although I think some of them were built on a more elaborate scale than necessary, merely to be sure that the gas would be thoroughly cleaned. In nearly all the gas-washing plants I am familiar with, the amount of dirt in the gas after washing was found to be less than that in the air. Extra precautions were naturally taken in designing our first gas-washing plants on account of the large percentage of fine ores that usually compose our blast furnace burdens, but in every case the gas cleaning was found to be very thorough.

Blast furnace gas, like any other gas, has a saturation point for moisture, depending on its temperature. If it is cooled down low enough it can only contain a fixed amount of moisture, depending on its saturation point, except the moisture which is mechanically contained, and any such moisture is very easily removed with a few baffles in the gas flue. Elaborate dryers are not usually required.

The thermal efficiencies for the gas-engine plant of approximately 23 per cent are all that could be expected under the conditions. Higher values have been obtained in tests, but for continuous work the plant efficiencies obtained by Mr. Freyn are very creditable.

Gas Engine Development. As Mr. Freyn states, the Lackawanna Steel Company was the first to attempt a large blast furnace gas engine installation in this country. They adopted the two-cycle Koerting engine, built in this country from German designs. The United States Steel Corporation decided in 1904 on an initial installation of blast furnace gas engines at the Edgar Thomson furnaces of the Carnegie Steel Company, which was followed by other installations. After a thorough investigation of the various types of engines used abroad the officials of this company decided that the four-cycle gas engine would be best adapted for their use, and that in designing such an engine the lines and construction of the modern heavy-duty American steam engine should be followed as nearly as possible, as this type of engine had proved universally successful. They also endeavored in the design of these gas engines to eliminate as many complications as possible and to arrange all parts so as to be easily accessible for removal and replacement. All the firms starting to build blast furnace gas engines in this country at the time preferred the center-crank construction in place of the American side-crank construction which has proved itself so successful and convenient. It was decided that an over-hung crank gas engine could be made strong enough and that these engines should be of this type. The heavy American rolling-mill engine frame was also insisted upon. The

Westinghouse Machine Company, in coöperation with the engineers of the Carnegie Steel Company, designed our first engines along these lines.

The Snow Steam Pump Works, the Allis-Chalmers Company, and others who were starting into the blast furnace gas-engine business also realized the importance of building along American lines and should be mentioned in connection with the development of a successful gas engine suitable for American blast furnace and steel works practice. I do not mean to detract in any way from what our friends abroad have done in developing the gas engine, as we are greatly indebted to them. It required a great deal of courage to go into this business on such a large scale, knowing that these engines would have to prove just as reliable prime movers as modern American steam engines, which have been years in reaching their present state of perfection.

The Carnegie Steel Company had built a small tandem gas engine, 21¾-in. diameter cylinders and 30-in. stroke, as nearly along the designs of the larger units as possible. This engine and a 250 h.p. direct-current generator were temporarily installed for experimental purposes at the Edgar Thomson furnaces and were started December 9, 1905. This unit was run continuously under all kinds of conditions and numerous tests were made on it. The information acquired from this experimental engine helped in perfecting the designs of the larger units.

Different Systems of Governing. At that time it was a great question as to whether a gas engine should be governed by the constant-mixture system or by the constant-compression system. The constant-mixture system, brought to so much prominence by Mess in Germany, consists of governing the mixture of air and gas admitted to the cylinders so as to have an explosive mixture that will readily ignite at all loads, although on light loads the compression must necessarily be greatly reduced.

The constant-compression system consists in admitting an excess of air into the cylinder with the amount of gas required for any particular load, so that on light loads nearly the same compression will take place as on heavy loads. Efforts were made to stratify this mixture in the vicinity of the igniters so that it would readily ignite on light loads. To effect this stratification many complications were necessarily resorted to.

A trial of the constant-compression system proved that when there was no load the charge could not be depended upon to burn and

that at other loads the indicator cards showed a marked difference in area from one explosion to the next at exactly the same load. The full-load cards were the only ones to reach the proper shape. These conditions are characteristic of this type of governing and are due to imperfect combustion at loads under the full rated load of the engine. With the constant-mixture system, however, the cards were of proper shape at all loads, and of the same area for equal

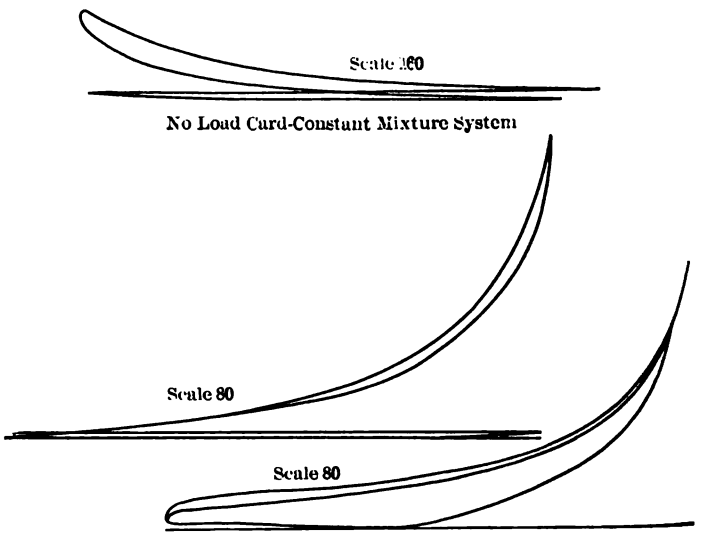


FIG. 44 COMPARISON OF CONSTANT-MIXTURE AND CONSTANT-COMPRESSION CARDS TAKEN AT NO LOAD

THE TWO LOWER CARDS SHOW THE UNCERTAINTY OF THE CHARGE BURNING AT NO LOAD WITH THE CONSTANT-COMPRESSION SYSTEM. IN ONE CASE THE AREA IS NEGATIVE AND REPRESENTS ONLY THE COMPRESSION LOSS DUE TO A POSSIBLE LEAK. WHILE THE OTHER HAS A POSITIVE AREA, THE COMBUSTION IS NOT WELL TIMED. THESE CARDS WERE SELECTED AT RANDOM FROM A LARGE NUMBER.

loads. (Figs. 44, 46 and 47). Continuous indicator cards showed absence of misfiring at no load and with a compression not over 65 lb.[1]

From the small experimental engine which helped to demonstrate these points, it was found that on light loads with constant compression the charge would not ignite for periods, the engine

[1]Continuous cards were submitted with the discussion which have not been reproduced for publication.—EDITOR.

uld slow down slightly, then take a large gulp of gas and air and
; for a short period and so on, so that it could not be depended on when light or extremely variable loads were being carried.
We therefore adopted the constant-mixture system and have tained excellent results. It may not be quite as refined and econom-ıl as the constant-compression system, but it is better suited for this ıss of work, particularly on variable loads, although under some nditions excellent results are no doubt obtained with the latter.

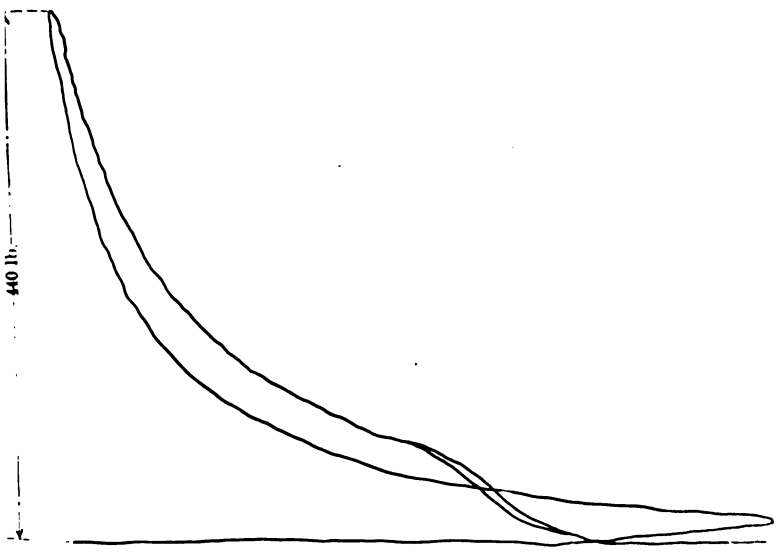


FIG. 45 INDICATOR CARD SHOWING PRE-IGNITION, RESULTING IN A PRESSURE OF NEARLY 500 LB. PER SQ. IN.

CARD SHOWN FULL SIZE; SCALE OF SPRING 160; MAXIMUM CYLINDER PRESSURE RECORDED.

It does not seem natural, especially with a four-cycle gas engine, to draw in a very lean mixture of air and gas, compress it to the usual full-load pressure of 200 lb. into a comparatively small volume, and then expect to have the mixture stratified in the vicinity of the igniters so that it can easily be exploded.

Gas Engine Operation. The installation of gas engines at the Edgar Thomson furnaces consisted of two Westinghouse twin-tandem gas blowing-engines, 38-in. diameter and 54-in. stroke, and one Westinghouse twin-tandem unit, 40-in. diameter and 54-in. stroke, for driving a 1500-kw. generator. The first blowing engine was started

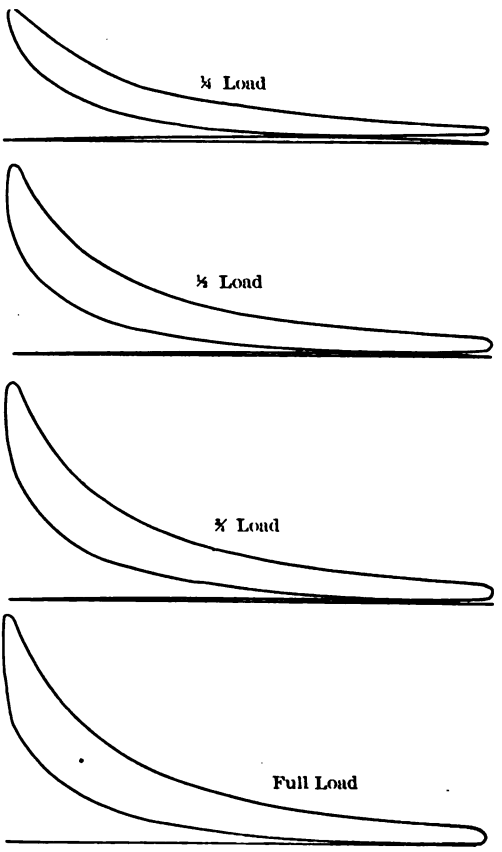
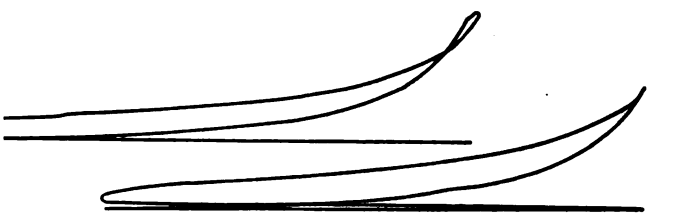
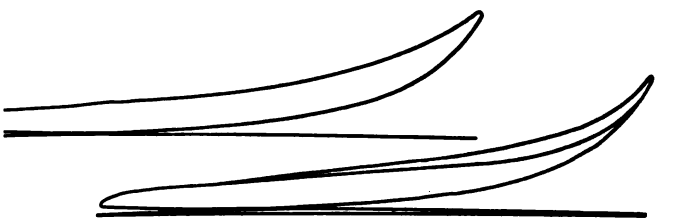


FIG. 46 CARDS TAKEN ON THE EXPERIMENTAL ENGINE OF THE CARNEGIE STEEL COMPANY, WHEN OPERATING ON THE CONSTANT-MIXTURE SYSTEM

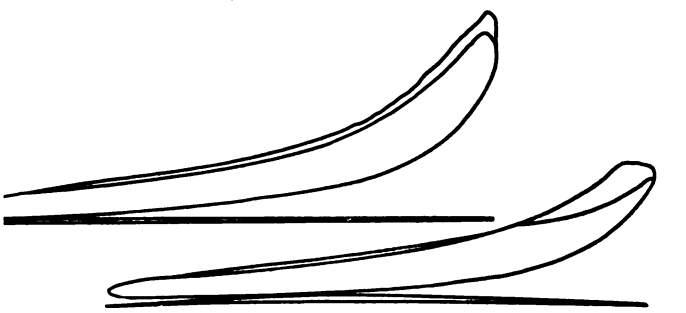
THESE ARE TO BE COMPARED WITH THE CONSTANT COMPRESSION CARDS SHOWN IN FIG. 47. IN BOTH SERIES THE LOADS WERE MAINTAINED CONSTANT AT THE DIFFERENT PERIODS. IT WILL BE NOTED THAT THE AREAS OF THE CONSTANT-COMPRESSION CARDS VARY FROM ONE EXPLOSION TO ANOTHER AND THAT THOSE TAKEN AT FULL LOAD WERE THE FIRST TO REACH THE PROPER SHAPE. THIS IS DUE TO THE IMPERFECT COMBUSTION AT ALL LOADS UNDER THE FULL OR RATED LOAD, A CHARACTERISTIC OF THIS SYSTEM OF GOVERNING.



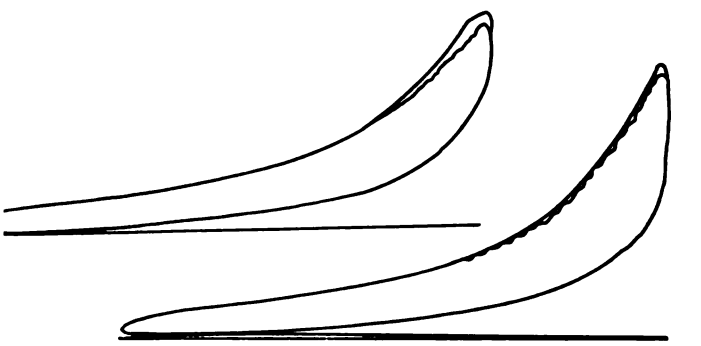
Cards at ¼ Load



Cards at ½ Load



Cards at ¾ Load



Cards at Full Load

CARDS FROM THE EXPERIMENTAL ENGINE TAKEN ON THE CONSTANT-COMPRESSION SYSTEM

on December 7, 1906, and the others followed soon afterwards. From the operation of these engines and from many others that have since been installed, much valuable information was acquired and many improvements in design have followed. All the difficulties encountered since the starting of this plant have been met and overcome and in 1909, No. 1 blowing engine ran 8241 hours out of 8760, or 94 per cent of the time; No. 2 blowing engine ran 8186 hours out of 8760, or 93.5 per cent of the time; and No. 1 electric engine ran 7075 hours out of 8760, or 81 per cent of the time. I would consider these records very good even for the best type of steam engines.

Lubrication. Great care should be exercised in selecting proper gas-engine cylinder oil and the oil used should be carefully tested. An oil showing the following analysis has been found to be very satisfactory:

Specific viscosity (compared with water)	4.10
Flash point, deg. fahr	530
Burning point, deg. fahr	600
Deg. Baumé (sp. gr. 0.880)	28

An important test can be made by filtering oil through filter paper, to see if there is any carbon deposit in the oil. This is often due to the temperature of distillation being too high, or to the distillation being carried too far, or to the imperfect filtration of oils that have been heated too high. Such oils will frequently break up and deposit carbon, rendering the oil utterly unsuitable for gas engine use. It is unnecessary to say that a paraffin base oil should be used and never one with a tar base.

Our method of oiling cylinders is to pump the oil in when the crank is 50 deg. early of the forward center-line on the suction stroke. There are two oil holes on each end of each cylinder, 30 deg. on each side of the centre. With this arrangement the oil runs down the cylinder walls and is wiped over by the piston.

Ignition Systems. Mechanical make-and-break and electrical make-and-break ignition systems are used and both work very satisfactorily, but as much care as possible should be taken to make an even distribution of the igniters around the cylinders.

Indicator cards taken with one, two and three igniters working show plainly the better efficiency obtained with three igniters in operation. With blast furnace gas it takes time for an explosion to propagate. This is plainly shown by our being compelled to have the igniters fire from 30 to 35 deg. before the crank pin passes its center.

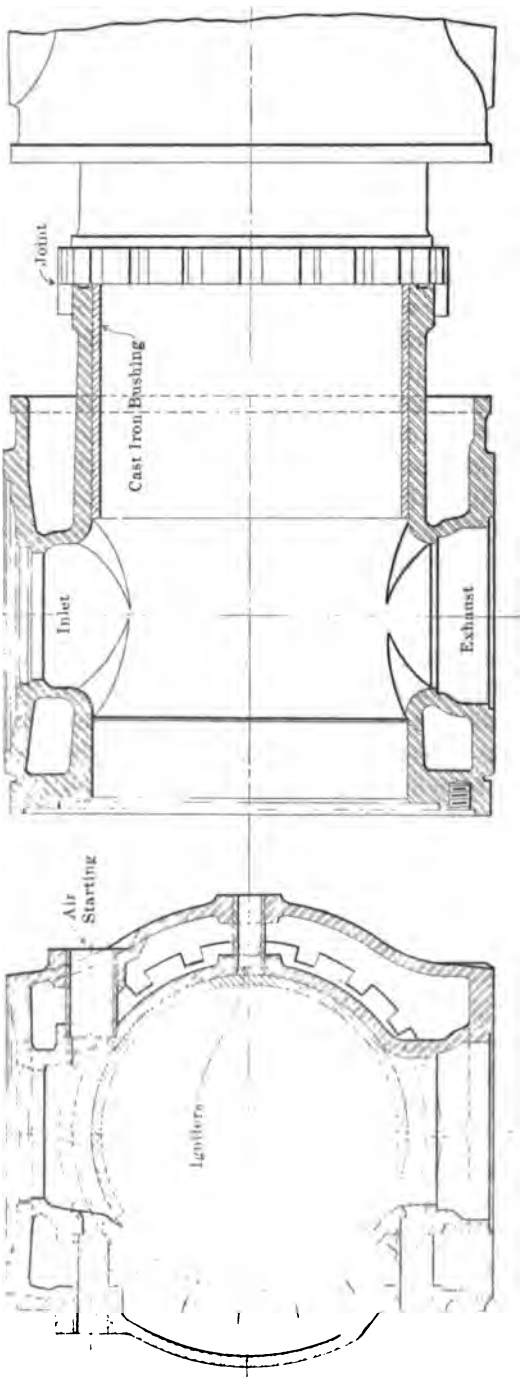


FIG. 48 CAST-STEEL CYLINDER FOR 40-IN. BY 54-IN. GAS ENGINES

If the igniters are all on top of the cylinder, or all on the sides or bottom, most of the wear is on these points, due to the explosion pressure getting under the rings sooner and being greater at these points.

Gas Engine Conditions. As is well known, the very high explosive pressure at the beginning of the piston stroke subjects the pistons and ends of the cylinders and cylinder heads to severe pressure and temperature conditions, requiring them to be carefully water jacketed and designed to take care of expansion. A blast furnace gas engine, even with these high explosive pressures, rarely averages over 65 lb. m.e.p. in the cylinders.

In Fig. 45 is an indicator card showing pre-ignition. The pressure is nearly 500 lb. per sq. in. and in some cases these pre-ignition pressures might be higher. With a 44-in. diameter piston it can be seen that while the explosive pressure continuously transmitted through the working parts of the engine is always large, an additional pressure of 1,000,000 lb. may suddenly be put on the crank pins by pre-ignition. This is why many difficulties such as cracked pistons, heads and cylinders, lubrication troubles, etc., have been encountered, especially on the larger size gas engines. These difficulties, however, are all being overcome and high-class gas engines of large power have been the result.

Gas Engine Cylinders, Pistons and Heads. The proper water cooling of cylinders, pistons and heads is very important, especially for large engines. The cylinders should have ample waterjacket space between the main cylinder and the outer water jacket should be well fitted with hand holes so that mud deposits can be thoroughly cleaned out.

Fig. 48 shows the design of a cast-steel gas-engine cylinder. It has been the aim to make this as simple a casting as possible. The ends next to the explosion were cast down so as to get the best material in that part of the cylinder. It has usually been the practice to make these cylinders of cast iron and with this construction large cylinders required walls approximately 4½ in. thick to resist the heavy explosive pressures. The cylinder shown is of cast steel, bushed with a 1-in. cast-iron bushing, arranged so as to be free to expand lengthwise. This bushing can also be easily removed and replaced.

The cast-steel cylinder construction permits us to decrease the thickness of the cylinder walls without decreasing the strength through the cylinder. By this means the water cooling can penetrate much closer to the hot cylinder walls, thus drawing the heat from these vital parts and preventing fatigue of the metal at each end of the cylin-

r where the heavy explosions take place. This fatigue of the cylin-
r metal is still more pronounced on gas engines operating on some
the richer gases.

There have been some difficulties due to the cracking of gas-
gine pistons and cylinder heads, but usually these have been caused
omitting to make the proper provisions for the increased strains
d temperature conditions which they are required to stand. In
ost cases the pistons and heads are now made from cast steel for
e larger size gas engines, which permits lighter walls and much
ore effective water cooling.

In all cases the weight of pistons and rods of gas engines should
carried on the crosshead and slippers. The pistons should have
least $\frac{1}{16}$-in. clearance all around the bore of the cylinder, thus
aving only the friction of the piston rings on the cylinder. These
ngs should be fairly wide and deep and held in place by good strong
rings and keepers.

Since our engines have been in operation there has been only one
se where we have cut a cylinder, and this was due to a water leak.

JOSEPH MORGAN. The Cambria Steel Company has made a small
ginning with one gas engine to determine the best way of purifying
e gas and also to determine a good type of blowing engine. There
always an experience account in operating plants, which commenced
ith us when we blew in our No. 7 blast furnace. On the design of
n engineer of large experience, we had provided two down-comers for
e furnace, each with a large dust-catcher. These dust-catchers
ere of the usual shape, about 22 ft. in diameter in the cylindrical
art, with a cone top and bottom and a fairly large cubic capacity.
he down-comer originally entered radially into the cylindrical part
ointing downward, at about the same angle as the bottom cone. The
as to boilers and stoves was taken off at the top of the upper cone,
nd we relied on the large capacity of the two dust-catchers to allow a
ettlement of the heavy dust to the bottom of the cone, but somewhat
o our surprise we got very little dust from the dust discharge openings
nd very great quantities of dust in the stoves and boiler chambers.
he cause was the action of the heavy volume of gas entering the
hamber which, being directed to the center and downward, kept the
irt stirred up from the bottom cone and allowed no settlement. At
he first stoppage of the furnace we changed the entrance of the down-
omers to a tangential connection in a nearly horizontal direction
nto the upper part of the cylinder, with the result that the dust caught

was largely increased. We also added brick cross-walls on the bottom cone, so that the discharge opening was not closed, but which prevented a current of gas in the bottom cone from stirring up the dust. The dust that came down into the bottom cone was caught in this lower chamber. This detail added to the efficiency of the dry dust-catcher. The resulting increase of efficiency was a valuable lesson on the effect of centrifugal force in separating dust, and the necessity of keeping the gas currents from stirring it up again. In recent improvements on several furnaces we have also added in series with and also following the first dust-catchers, a horizontal dust separator in which the principle of dry centrifugal separation is made use of. We have this apparatus at work on two furnaces, one of which supplies our gas engine.

This horizontal separator contains a helical gas-passage through which the gas flows. Each turn of the helix has at its bottom a dust-trap so that the dust carried by the centrifugal force to the outside of the helix goes tangentially into the traps from which it is drawn when necessary. This helical separator traps about ten to fifteen tons daily in addition to that stopped by the large dust-catchers and takes out about 70% of the dust remaining in the gas after leaving the first dust-catcher. The indications are that five or six helical turns are sufficient.

This completes the dry separation, which in our plant it is desirable for reasons of cost to make as complete as possible without the use of water, as the dust runs freely from dust-pockets when dry and is therefore handled more cheaply. In our earlier experience we tried several types of wet separators near the furnace, but the great volume of wet dust added largely to the cost of handling. We believe the large quantity of very heavy dust should be taken out as far as possible by dry separation, and that water should be used after the gas has somewhat cooled by radiation. This lessens the quantity of water necessary for final cooling and is another economy.

From this separator the gas is taken direct to the stoves and boilers, but for the experimental gas engine we have installed a pair of Schwartz revolving centrifugal washers, somewhat similar to the Theisen, which are used in series. The water comes out from the first very muddy, while from the second it is very limpid, showing that the former takes out most of the dirt, and the latter perfects the operation. This is perhaps a temporary arrangement, as we have no static cleaners other than the dry dust-catchers or cleaners already described.

The engine under trial at our furnace is a double, horizontal, ndem gas-engine with four gas and two blast cylinders, built by e Southwark Foundry Company of Philadelphia. It is novel in veral details, all of which have proved of value on trial, as adding the speed of running and the ease of manipulation. The blowing linders are fitted with gridiron slide valves of the well-known outhwark type for inlet and outlet of blast. All the valves for both ir and gas cylinders are actuated by the straight-bar reciprocating am of the Southwark type, which allows great facility for adjustment f the cam not found in arrangements of those on rotary shafts. The ngine can easily be run at 70 revolutions, a much greater speed han is attainable with ordinary blast valves. This lessens the cost f engine installation or increases the quantity of available air from cylinder.

In addition, there is a tripping device by which the blast inlet alves at one or more of the four ends of the blowing cylinders may e put out of action and left open, thus partly or wholly unloading he engine in starting up or when the furnace needs less blast or even one. This greatly facilitates the starting and manœuvering of the ngine, as it need not be started under load or be stopped at casting imes or to slacken blast.

The other departure from former designs is in the gas-entrance nd exhaust valves. The gas cut-off valves located on top of the cylinlers are tripped by the action of magnets, the current for operating hich is timed by the governor action. The exhaust valves are located o that they are very conveniently accessible, being at the side of the ylinder and above the floor instead of under the floor, as in many as engines heretofore built. This has been found good practice and here are no difficulties arising from this unusual location. Heretore it has been supposed that particles of dirt would be more effiiently swept out of the gas cylinder if the exhaust opening were irectly under the lowest part of the cylinder, in which case the xhaust valves are not easily accessible.

The very full and complete paper of Mr. Freyn, with its voluminous report of working results, is an admirable and valuable addition to the literature of blast-furnace gas engines.

H. G. Stott. The problem of the cleaning of gas is similar to that of removing the moisture from steam. At the 59th Street Station of the Interborough Rapid Transit Company we first used an elaborate system of separators between the engine and the low-pres-

sure turbine. The separator contained a series of baffles, which was supposed to take care of a certain amount of m These baffles became loose and in order to keep the machine i tion we removed them. The result was an increase of 4 per the efficiency of the separator. A new separator was designed cause a sudden reduction in the velocity of the steam and we o a quality of 97 per cent. I believe the same principle applie elimination of dust from gas and that the real separation is by the sudden reduction of velocity.

I found from tests on the combined unit of reciprocating and steam motors that the thermal efficiency works out identical with Mr. Freyn's results, a little over 21%, t ranging from 7000 to 15,000 kw. Any steam motor has the im advantage over the gas engine that it gives a wide range of o with an efficiency curve that is almost flat. The burning of g boilers is a very much more efficient operation than the burnin and quite remarkable results have been obtained with gas-fired It would be interesting to note the results of so using the b nace gas and supplying the steam to the combined engine and unit.

EDWARD A. UEHLING. One of the most important part Freyn's paper deals with the cleaning of gas, a phase in blast construction and operation that has been most sadly neglecte past and even to day is not fully appreciated except where t to be utilized in the gas engine. But because of the dirt car the stoves by the gas their efficiency is greatly reduced, and up the deficiency in blast temperature a fourth and not infre a fifth stove has been added.

The cost of the additional stoves would have been mor ably expended in efficient gas-cleaning apparatus, becaus results could be obtained from three stoves supplied with c than from four or even five stoves mucked up by dirty gas. T few stoves in existence in this country to day whose heating and consequently heating capacity, could not be quadru thoroughly cleaned gas was available. This also holds for th connected with blast furnace plants; in most cases their outp be very much increased and their efficiency doubled if serv clean gas.

It is worse than useless to line gas mains and a great money could be saved, not only in refractory material, but

he metal parts of the main and their supports. There is no excuse or the gas coming off from the furnace at a temperature so high that t will injure an unlined gas main. By applying water, preferably to he stock as it is charged into the furnace, the gas temperature can lways be kept below 400 deg.

I have been one of the advocates of the blast furnace gas engine for a great many years. Before anything had been done along this line I calculated that there was 800 h.p. available above the needs of the plant for every ton of iron produced in 24 hours. Mr. Freyn has actually obtained about 600 h.p., showing that better results may yet be obtained.

S. K. VARNES[1]. American practice in blast furnace gas cleaning has simmered down to the three-phase process. The gas is first passed through dry preliminary cleaners, then through stationary wet scrubbers, and finally through rotary wet scrubbers. The gas is used for two purposes: it is burned in stoves and boilers or used directly in gas engines. Each of these uses requires gas of different characteristics. It has been found in German and American practice that gas containing from 0.15 to 0.20 grains per cu. ft. is sufficiently clean for boilers and stoves and it has been reported that dirty stoves can be cleaned by the use of such gas. For gas engines, however, one-tenth of this amount is all that is permissible.

In a number of cases it has been found that one centrifugal dust catcher removes 85 % of the dust which may be caught by the dry method and a second one is practically a waste of money.

Most of the secondary cleaning in the United States is done by a series of different types of washers, although at Steelton the secondary stage has been reduced to a single piece of apparatus. It is the secondary or stationary wet-scrubber stage that I wish to mention especially.

I believe the first blast furnace gas engine to be operated in America was that at Steelton, a Westinghouse vertical engine, using a coke-filled scrubber to clean the gas. The enormous quantity of dirt promptly filled the scrubber, and the difficulties with engine operation were similar to those experienced at Lackawanna, due to lack of cleaning.

The most recent development of the scrubber may be said to be the Zschocke washer, built originally in Germany and, with modifica-

[1] Experimental Engineer, Pennsylvania Steel Co., Steelton, Pa.

tions, much used in the United States. The primary washers described by Mr. Freyn are of this type. It is a type of scrubber in which an attempt is made to limit by the mechanical design the exact relation between the voids of the scrubber and the solid matter, consequently fixing the relation between the water contact surface and the area of the gas passages.

It would seem, however, to be a waste of money to build a tower of a certain size and then partially fill it with solid materials, thereby increasing the velocity of the gas through the tower and decreasing the time allowed for cleaning. If it were possible to present the same water contact surface and accomplish the same mixture of gas and water, and still maintain the full area of the tower, or very nearly so, it would be an advantage. This result is obtained by the sprinkling type of tower in which the grids or hurdles are eliminated and the water is caused to descend through the tower in drops. Of prime importance in this type of tower, however, is the uniform distribution of water and the breaking up of the water into sufficiently small particles. In case a particle of dust be brought into contact with a film of water, as in the Zschocke washer, if the dust particle is sufficiently small it may not be able to pierce the water film, due to the resistance of the surface tension of the water. Consequently, if the size of the drops of water be reduced to a point where they become much smaller than the size of the dust particles, the water particles will envelop the dust particles, weigh them down and carry them downward by entraining action, depending on the increased density of the dust particles with the film of water. The question of attaining this theoretical condition has been a difficult one.

The Mullen washer and the Moyer washer, which is a modification of the Mullen washer, are known as impinging types of washers. The gas comes into the top of the chamber, passes down through tubes, impinges upon a water surface, and then goes off in a reverse direction. The efficiency of such an apparatus as a gas cleaner, so far as dust is concerned, has been found to be very good, but the gas is not cooled in its passage through this scrubber, and frequently leaves at a temperature of about 300 deg. Gas at 300 deg. can contain about 260 grains of water per cu. ft., and gas at the ordinary atmospheric temperature can contain only five to seven grains per cu. ft., depending on the temperature. When this entrained moisture is carried into the stoves and boilers, it must be evaporated except for that which has been condensed on the way over. The loss is very material, and I know of one plant using a changed form of the Mullen washer

hat has abandoned its use in the original form because of the ncrease in the moisture content of the gas. If it were possible to ool the gas after the impinging action, it would be a very efficient ype of scrubber.

The plant of the Pennsylvania Steel Co. consists of a single type of apparatus for each of the three stages. For the first stage a centrifugal dust catcher is used; for the second, two similar sprinkling-type wet scrubbers; for the third, two similar rotary wet scrubbers. The plan of the cleaning plant is shown in Fig. 49. The gas travels from *A*, the downcomer from No. 3 furnace, into *B*, the centrifugal dry dust catcher, out through gas mains *C* and *D* to inlet pipes *E* and *G* of wet scrubbers Nos. 1 and 2 respectively. Leaving these scrubbing towers the gas may be taken off at one side through *H* to the rotary scrubbers or through *F* and *L* to the gas main *M* supplying stoves and boilers. An alternative course is provided from *E* through wet scrubber No. 1, out at *F*, thence to *G*, and through scrubber No. 2 to *H* or to *L*. The wet scrubbing plant may be by-passed to get gas to the stoves and boilers. The valves *V* are all water sealed. It is seen that the wet scrubbers may be operated in parallel (as originally intended) or in series if found necessary.

The scrubbing towers are each 25 ft. in diameter by 60 ft. high. The elevation is shown in Fig. 50. Gas enters through the brick-lined flue *A*, impinges upon the water seal surface *B*, passes up through the tower *C*, meeting there the rain descending from the distributor above and leaves at *D* or at *E*. The gas flues are brick lined as far as the towers, and the dry dust-catcher is brick lined except for some cast-iron wearing plates, in order that the gas may arrive at the tower as hot as possible. The hot gas immediately upon impinging upon the water seal gives up a portion of its heat in evaporating water which is quickly condensed by the rain from above. When this evaporated water is condensed from a gas to a liquid it necessarily passes through a state when the water particles are smaller than the dust particles carried by the gas and will attach themselves to the dust particles in condensing, thoroughly wetting them and weighing them down. In this condition they are readily washed out by the rain through which they are compelled to pass in ascending the tower. The distributor used in this tower for distributing water (Fig. 51) has been the subject of a great deal of study and experimentation, and consists of a steel shaft *A*, extending through the top of the tower, with a bearing *F* on the outside, carrying at its lower end a wheel, the frame being of pipe work, and on the horizontal top surface *C* a screen of

about ¼-in. mesh wire. This screen is rotated, water is brought at the top through the nozzles *D*, bent at an angle of 90 deg., that the water strikes the screen tangentially, at an angle to

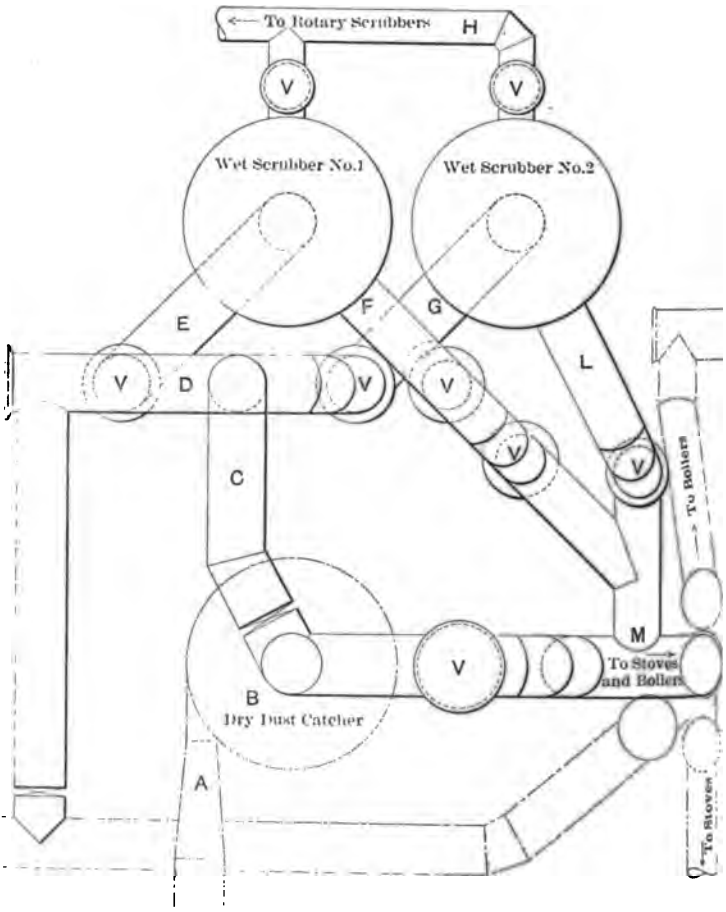


FIG. 49 PRELIMINARY GAS-CLEANING PLANT

radius, and opposite to the direction of rotation. This arrangem gives a practically uniform distribution.

Some of the advantages of this distributor are that there is resistance to the passage of the gas from the bottom of the towe the top, there being no obstruction whatever. It is possible by m

ıholes to get at this single screen and clean it in case of obstruc-
The water nozzles are all connected to a manifold on top of the
and are readily removable from the outside for cleaning in case
gging. The water is carried to this manifold at about one

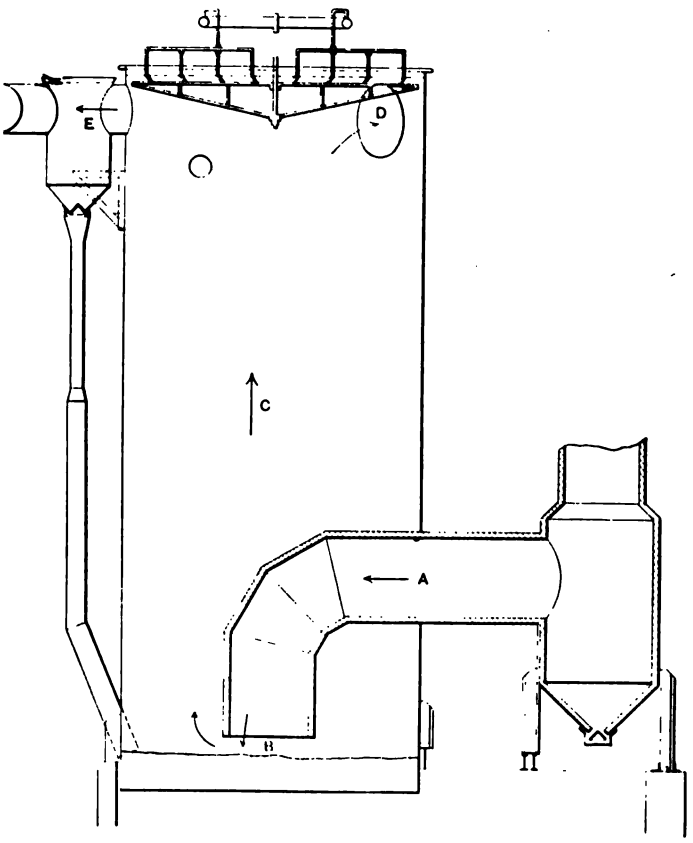


FIG. 50 SCRUBBING TOWERS

d pressure, just enough to lift it to the top of the tower. When
as leaves the tower it is hoped to have it sufficiently clean to go
: stoves and boilers. It has been found in one scrubber tower that
built with a distributor, not of this type, but giving practically
ırm distribution, that the gas was sufficiently clean for stoves and
rs in one operation, and we feel that we will be able to do the

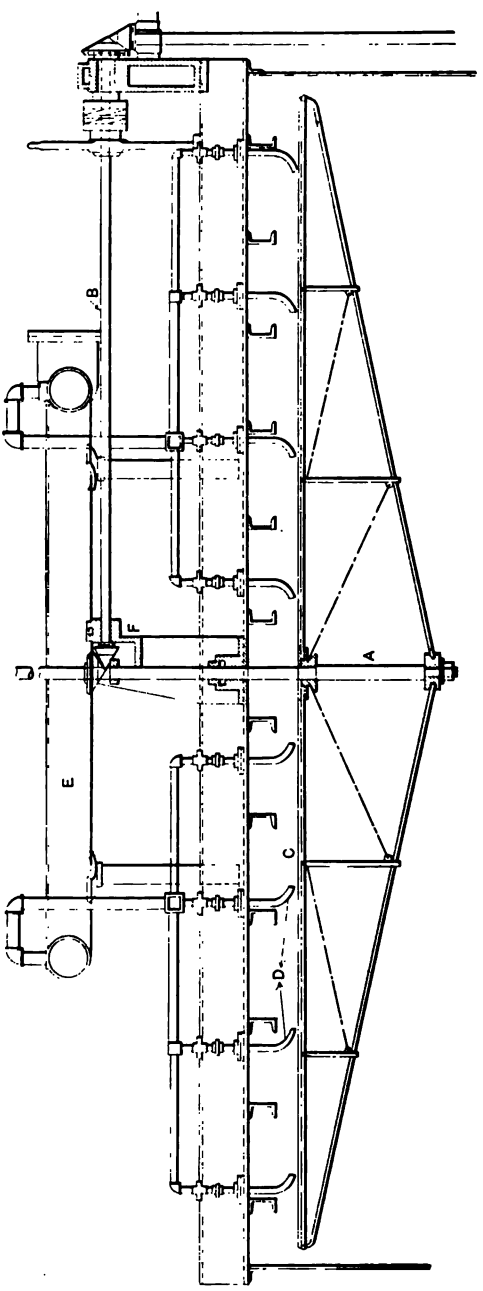


FIG. 51 WATER DISTRIBUTOR IN SCRUBBING TOWER

ıe thing. As there is no resistance to the passage of the gas ɔugh the scrubber, it should not be necessary to put in fans to force gas to the stoves and boilers.

'he gas from *H* goes to the secondary washers. For this opera- ı I think there is no doubt that the Theisen washer will solve problem very successfully.

I. G. H. TARR.[1] During a recent trip to Germany I visited some the larger iron works and was interested in observing the differ- ːes that exist in their method of preliminary gas cleaning. It is ɔbable that this arises from the difference in ores and materials ated, as much as from the opinions of engineers as to the best thods. For final cleaning, however, the Theisen washer is quite ensively used. I was told in England, as well as in Germany, that ı was being delivered to the engines through these washers in a ;her state of purity than existed in the air, and this seems to have ːn borne out by experiences in this country. There is a very great ɔbability that the time is not far distant when the air will be washed, well as the gas.

This leads to the thought that this method may be adopted for aning the air entering churches, hospitals, theatres and wherever ːre are large assemblies of people.

EDWARD RATHBUN. Probably the most serious thing we have to nsider as engine builders regarding producer gas engines is the estion of gas cleaning, or to be exact, the cylinder wear, and in ɲjunction with the valuable information contained in Mr. Freyn's per, I would very much like to see some data regarding the relative ːar of the engine cylinders as the various cleaning processes were veloped.

JESSE M. SMITH. When I was building blast furnaces in central ıio, prior to 1880, we were smelting native ore with raw bituminous al containing a tremendous amount of dust, which not only stopped ɔ the flues, but also the space below the boilers and in the ovens. ɔ remove this difficulty we discharged the dust vertically downward ɔm the blast furnaces into a cylindrical chamber 12 ft. in diameter ıd water-scaled at the bottom. This chamber was several times ːger than the down-comer. The gas ladened with dust came down

[1] R. D. Wood and Co., Camden, N. J.

against the water and the major part of the dust was caught, to be removed through the water seal. This apparatus worked admirably and after its installation we were not troubled with dust in flues, under the boilers or in the stoves.

I have found in this connection, as well as in the cyclone dust catchers used in flour mills, where the centrifugal motion is used, that final separation of fine dust from air or gas must take place, as Mr. Stott has said, by sudden reduction of the velocity so that the gas has an opportunity to deposit its heavy portions on a surface that will catch and hold them.

CHARLES WHITING BAKER. To obtain clean gas for engines, the use of a water spray results in great reduction of temperature. It is also possible that in modern practice where very fine ores are used, it may be necessary to employ water for cleaning the gas to be used under stoves and furnaces. The 300 to 400 deg. of heat lost in the cleaning process would be worth while saving if we could discover some means of dry cleaning the gas. It is entirely possible that by using the dynamic process or the type of cleaning used in flour mills the gas might be dry cleaned and delivered to the stoves and furnaces at its original temperature.

E. P. COLEMAN. As stated in Appendix No. 5, contributed by Mr. Bacon, certain liberties were taken in the design of the 60-in. venturi meter, in that the junction between elements of the upstream cone and the cylindrical throat is angular, not being formed by means of an easy curve as is usual. By referring to Fig. 23*b*, it will be further observed that the distance from this angular junction to the $\frac{3}{16}$-in. holes communicating with the angular pressure-chamber is relatively small. The coefficient of 0.91 for this meter as determined by means of the gasholder, is in all probability correct, but it is believed that, if the junction had been rounded, or the $\frac{1}{16}$-in. holes situated farther downstream from the angular junction, or both, that the coefficient would have been greater. In addition to the probable eddy loss noted by Mr. Bacon, it seems probable that a contraction of the stream also occurs at a point in the stream opposite these holes. Each of these conditions, if existing, will lower the coefficient. By rounding the junction the eddy loss is reduced; and by locating the pressure holes at a section of the throat which is filled by the stream, the pressure difference should more closely approximate the ideal.

Considering the extraordinary facilities provided by the 100,000-. ft. gas holder for determining accurately such coefficients, it seems ıfortunate that commercial reasons were allowed to affect the design. ıe writer believes that a venturi meter of 6 in. diameter or more, and the best design and construction, will show a coefficient greater than ı% with usual gas velocities.

A. BEMENT. While the successful outcome of the plant described y Mr. Freyn is cause for congratulation, it is probably correct to say ıat if the application of the gas engine in connection with blast furaces had been delayed much longer it might have found very strong ompetition in the gas-fired boiler supplying steam to turbines di-ect-connected to electric generators and to blast furnace blowing-ngines.

Relative to safety devices, the writer believes their use in all ossible cases to be desirable, and is inclined to the belief that the eeling of opposition to them is based upon the assumption that they ill be expected to take the place of manual supervision. Where afety devices have been successfully employed with delicate electrical ıpparatus. marked success has been secured. It was necessary, how-ver, that the apparatus be watched and kept in order. Its use is not o take the place of the watchfulness of the men, but as supplement-ng it.

Contrary to expectation when the use of furnace gas in engines as proposed in Europe, it has been found that the removal of dust rom the gas is a matter of the greatest importance. This is especially rue in this country because of the finer ore and harder driving of urnaces. In this connection dry air bla-t promises to effect a marked eduction in the amount of dust carried by the gas, as its use appears o result in a very much more even working of furnaces and a very narked reduction in the number of slips.

W. E. SNYDER. This paper is without doubt the best description and operating record of a blast furnace power plant that has ever been publ shed, and great credit is certainly due the broad-minded officials of the company operating this plant for their action in making the data available. Great credit is also due to Mr. Freyn for the very complete records which he kept and for their very clear and thorough presentation. A discussion of this paper is possible only by considering the subject of the paper as a topic upon which others may add their experiences. I will discuss the paper in this way, giving

some notes relative to European operating experiences and comparisons with American conditions.

During the early part of 1908 I had the opportunity of investigating gas engine practice in almost all of the countries of Europe in which gas engines are used. During this investigation I visited 29 different plants on the Continent, and saw in round numbers 365,000 horsepower in operation. I also visited eight different works where large gas engines are built. At all of these plants I had opportunities for discussing their experiences with different engineers and operating men in charge. Although this was about two years ago, the development of gas engines and gas cleaning had at that time proceeded far enough to evolve certain standards of apparatus and methods of operation which have not changed materially since then.

The country which has made the most rapid strides in the development and use of large gas engines driven by blast furnace and coke oven gas is Germany. The first small gas engine to use blast furnace gas in Germany was put in operation in October 1895. In the early part of 1906 Dr. Reinhardt, of the Schüchterman and Kramer Works, estimated that there were then under construction or erection or in operation in German steel works 349 large gas engines, aggregating about 385,000 horsepower, and in German collieries 35 gas engines, aggregating 30,300 horsepower, a total of nearly 400 large gas engines. By far the larger proportion of these were installed during the period from 1902 to 1906. Other countries made contemporaneous progress, though not on such a large scale.

The effect of this rapid development in an entirely new field was that the early experience of many of the gas engine stations was one of continued and varied troubles. These troubles, while exasperating to the engineers in charge of operations and discouraging to the financial managers, constituted the experiences from which were evolved the very satisfactory European installations of the present day and the large installations in this country. European experience during this period of development, while very interesting, is of no importance compared with operating results from the more recent large gas engine installations, such as are given in Mr. Freyn's paper.

A feature of the use of large gas engines in Europe is the great confidence reposed in them by both builders and users. Gas engines were put in to work under the greatest variety of conditions, not alone for blowing blast furnaces and for electric driving, but for the direct driving of mills, of which I saw several installations, including merchant and small bar mills, rod mills and sheet mills. One steel

ant was equipped with a large gas blowing engine for the converrs. At two works some of the gas engines were so constructed that ey served for driving either blowing cylinders or electric generators i might be required. At other works a mixture of coke oven and ast furnace gas was used, or even producer gas and blast furnace as. In fact, there seemed to be no hesitation whatever in depending n the gas engine to operate under as widely varied conditions as the eam engine, and this confidence in what could be done with the gas ngine was usually justified by the results. Sometimes, of course, ere was a great deal of trouble and expense involved, but the work ent on without change in general plan.

The type of engine which seems to be the general favorite in urope is the same type that has been adopted for almost all of the nportant installations in this country. This is the four-stroke cycle, ither single or double tandem. There have been long and learned iscussions among the technical men of Germany on the relative erits of the two-stroke cycle and the four-stroke cycle engines, but he type which has predominated was not determined by these cademic discussions. It was determined by the engineers who were sponsible for operation and results.

Emphasis is everywhere laid on the necessity of good technical pervision over gas-engine power stations. As the prime requisite r good operating results, a good gas engine is specified; for the cond requirement, efficient technical supervision is provided, oupled with records of running conditions somewhat similar to ose presented in Mr. Freyn's paper, though not so complete.

The primary necessity for a good engine seems self-evident, but indicates the responsibility that is everywhere placed upon the ngine builder. The greatest troubles which develop are due to fire-acking of the cylinders and pistons. The design of those parts is ow much better understood than at first, with the consequent pre-ention of most of these difficulties. A very common size of cylinder the newer installations is 1100 mm. (43.3 in.) diameter and 300 mm. (51.3 in.) stroke. Each cylinder of this size at 95 evolutions develops about 1000 horsepower, which requires a m.e.p. f 56 lb. Cylinders of this size and smaller were made complete f one casting without a bushing. Since the time of my visit, however, ylinders have been designed and constructed to develop 1300 h.p. ach, approximately 52 in. in diameter by 56 in. stroke. There ave also been developed cylinders made of two or more castings stened together by strong and tight joints. This is to avoid the

difficulties due to shrinkage stresses and to the stresses in the casting caused by the difference in temperature between the inner and outer walls. Hard cast-iron bushings are also used, and some engineers are considering steel cylinders, if indeed they have not already been constructed.

These most recent developments in the construction of cylinders are very radical changes from what was the practice among leading builders but two years ago. Whether these changes are due in part to American experience or not it is not possible to say, but evidently the design of multicasting cylinders with bushings is due both in this country and in Europe to a common cause, the effort to increase the reliability of the cylinder, which result is certainly accomplished.

The operation of gas-engine-driven generators in parallel at 25 cycles was common, as was also their operation with steam-engine-driven units in parallel. The operation in parallel of two or more plants, gas or steam driven, but located at different places, was also practiced. Many of the newer units installed do not have flywheels, the entire flywheel effect being produced by the rotating part of the generator. The yoke frame is usually used, i.e., the main frame is designed with a bearing on each side of the crank. The various details, such as valve gears, regulating mechanism, igniters, etc., were in various stages of improvement, the object everywhere being to simplify and at the same time to retain or improve the efficiency and reliability of operation.

The newer installations in Germany are splendid examples of engineering accomplishment. This is true not alone of the gas engines, but also of the electrical apparatus, buildings and auxiliary equipment as well. Every detail seems to have been given attention, and where previous experience, or engineering foresight could serve as a guide, provision has been made for convenient and economical operation. One of the stipulations in contracts for gas engines now being installed is that after all adjustments have been made and the engine put into regular service it must run for four weeks continuously without stop or slow-down, and there is no difficulty whatever in fulfilling this condition.

With regard to the cleaning of blast furnace gas, there was almost every conceivable combination of dry dust catchers, vertical washers, and rotating washer devices, such as fans, Theisen machines, etc. Many works do not have Theisen machines in use for fine cleaning the gas, but use two or three fans in series. However, I did not hear any unfavorable criticism of the Theisen apparatus from any-

ne. The opinion was general that it was the most efficient method f fine cleaning the gas that had then been devised. Considering he gas cleaning proposition as a whole, from the furnace to the engine, did not see any installation superior to the best installations in this country, and I doubt if their equal exists in any of the European works. There is a reason for this in that the importance of cleaning gas thoroughly was fully realized in this country when gas engines were first considered, while in Europe it was at first thought that cleaning was not of much importance. The extended European experience with different systems and apparatus for cleaning gas for gas engines was available for the American steel works engineer when he first took this matter up, while there was no such experience available for the European engineer and all of the apparatus required had to be developed. There is a greater difference between the best gas cleaning plants in this country and in Europe than there is between the gas-engine power stations, or more particularly, the gas engines themselves. There is a strong probability that the reason for this is that here the steel works engineer, whether consciously or unconsciously, made more use of gas cleaning experience in Europe than was made of European gas-engine experience by the American designer. It is a fact that there has been practically no trouble here in the thorough cleaning of gas for engines in the principal installations, while there has been a great deal of trouble with the gas engines themselves in these same installations. Most of these difficulties have now been overcome, but many of them could have been avoided if the American designer had profited by the fund of European experience which was available when he first began his work.

The following may be given as interesting items of comparative data with reference to gas cleaning: Dr. K. Reinhardt found that the water consumption of Theisen machines varied in different plants from 22 to 60 gal. per 1000 cu. ft. of gas cleaned. The plant described by Mr. Freyn used an average of 19.4 gal. per 1000 cu. ft. Dr. Reinhardt also determined the horsepower per 1000 cu. ft. of gas cleaned by Theisen machines to vary from 0.17 to 0.37. Calculation from the data given by Mr. Freyn shows that the Theisen alone required 0.20 h.p. per 1000 cu. ft. of gas. German practice had come to regard 0.02 grams of dust per cu. m., equivalent to 0.009 grains per cu. ft., as a standard for cleanliness of the gas. This was a compromise between what was thought possible for a gas cleaning plant and what was desirable for gas engines. The average dust contained in fine gas for the year as given by Mr. Freyn's paper is

0.0058 grains per cu. ft. which is about 65 per cent of the approximate maximum fixed by German practice as standard.

The velocity of the gas allowed in the different mains and pipes as given by an experienced engineer was as follows: In large gas mains from 15 to 20 ft. per sec.; in smaller pipes connecting the different parts of the gas cleaning apparatus, 33 ft. per sec.; in branch pipes going to engines, 66 ft. per sec.; in valves and gas passages of the engines, 130 ft. per sec.

In some of the plants no charge was made to the power station for gas used. At many of the largest and most modern installations, however, a charge was made for the gas. This charge was determined by measuring approximately the quantity of gas used per month and calculating from its average composition the heating value of the gas per cubic meter. This was then evaluated by comparing with the heating value of standard coal used at the plant. In a few instances gas calorimeters were in use, but all instruments for measuring or testing gas were in process of rapid evolution and no method had general acceptance, either in the engineering or accounting problems involved in valuing the gas and accounting for it.

Venturi meters were not used in any plant for measuring gas. The usual method of determining the quantity of gas was to use an instrument based on the Pitot tube principle, the tube being located at a point in the cross-section of a straight run of pipe which has been determined by test to be approximately that of average gas velocity. The instrument was nearly always of the continuous recording type, with charts graduated to record gas velocity.

For lubricating the gas engine cylinders, the largest and heaviest types of lubrication that I have ever seen were in use. These lubricators were of very massive construction, and were frequently placed on the floor beside the gas engine, looking not unlike small vertical engines. They were connected to a number of oil pipes, which supplied lubricant to the cylinders, exhaust valves and rod packing. The cylinders were usually fitted with from four to six oil pipe connections, these being placed where, in the judgment of the designer, they would do the most good. It was not the practice to attempt to discharge oil in the cylinder at any particular point in the stroke. The method of driving the lubricator prevented this.

There was great variation in the kind of oil used, but the consensus of opinion agreed that the cylinder oil should be of light body, containing a minimum of heavy carbonaceous matter. The only test I could find being applied to oil for gas engines was that the smal-

r the residue when the oil was vaporized the more suitable it is for
s engines, provided that it has the general characteristics of good
bricating oil. At some plants they were using oil of the same kind
the cylinders as was used in the bearings and pins of the engine.

At many of the large installations great care is taken to provide
r the safety of the men in charge of the gas engines and gas cleaning.
arious kinds of safety apparatus are placed where they will be quickly
ailable in case of accident, and the men are trained in the use of
is apparatus. There are also rules in force which are intended to
omote safety conditions. One of these provided that no less than
o men shall work together, the presumption being that in this case
ere will always be one to raise the alarm in case a man is overcome
gas. Another rule provided for the proper ventilation of cellars
d the prevention of gas pockets about the foundation or building.
a result of these precautions accidents due to the effects of gas are
id to be very infrequent.

During the past two or three years very rapid progress has
en made in this country in the improvement of details, both in
e design and construction of engines and in their operation. Some
nerican engineers have done splendid work in designing large gas
gines to meet American conditions. One of the most important
provements is the cylinder made of two or three different castings,
ted with a hard cast-iron bushing. The use of steel castings for
linders is also an important development. It is not intended to
ply that these features of cylinder construction are distinctively
merican practice, but American conditions and designers are no
ubt largely responsible, since this form of construction developed very
on after the manufacture of large gas engines began in this country.

Another improvement in detail that is distinctively American
in the method of lubricating the cylinders. It is now very general
ractice here to have two oil pipes for each end of the cylinder, each
air being located at the top of the cylinder, one a short distance on each
ide of the center line. The oil pump is connected in such a way that
he oil is discharged at the beginning of each suction stroke where the
piston covers the oil holes. The lubricators used for delivering the
oil to the cylinders are much smaller and less cumbersome than those
in use in foreign plants and seem to be just as satisfactory. A system of forced-feed lubrication for all bearings, pins, etc., has been developed and is now in successful operation. This is of special importance in that it contributes towards higher piston speed, thereby reducing the first cost per unit of capacity and the floor space required.

The governing mechanism has also been improved to such a degree that all the principal builders are ready to guarantee successful parallel operation of 60-cycle alternating-current generators. This is also an improvement, but it came too late to influence the characteristics of the principal installations now in operation. At these plants the 25-cycle system was selected of necessity and must now be adhered to because it is too thoroughly established to permit of change.

Still another important improvement in detail which is distinctively American is the kind of cylinder used in large gas blowing engines. The blowing cylinders I saw on most of the gas engines of Europe, I consider the poorest part of the whole installation. A large proportion of these cylinders have the old type mushroom poppet valves for both inlet and discharge. While these may have been fairly well suited to the low blast pressures carried at most of the European plants, they are wholly unsuited to American conditions and to use them on gas engines here would be going back to the practice of 15 or 20 years ago. In order to get the most efficient results from a gas blowing engine, mechanically operated valves are necessary. This fact has been fully appreciated by American designers and some splendid examples of cylinders fitted with this type of valve have been produced. The equal of these American blowing cylinders with mechanically controlled valves is not made anywhere in the world and their use facilitates higher rotative speeds, which in turn reduces unit first cost and floor space. Speed control for blowing engines is a feature in which the best American engines equal the best used in Europe at present.

Gas cleaning, the construction of gas engines, and their operation are all now well understood in this country. The engineering problems involved are appreciated, even though they are not all solved. The commercial features involved are not of the most importance because a gas engine installation will in this country, for years to come, be a very expensive installation per unit of capacity. The price of fuel at all blast furnace plants in this country is low compared with what it is in Europe. The manager, in considering gas engines, must face the American aspect of high plant cost and low fuel cost. In this connection any improvements, such as forced-feed lubrication mechanically controlled air valves, etc., which facilitate higher piston speeds, are improvements which make the large gas engine more generally available for consideration in American plants. What is required is to increase the earning capacity of any given unit or

on. High load factor at nearly continuous operating con- one of the principal requirements for gas engine plants. It fore be seen that while a collection of data as given in Mr. aper is of great interest from an engineering standpoint, it particular importance in its bearing on the commercial use gines, i.e., it is a record of the efficiency or output of each part of the power plant, so that it is always known whether ne installation is maintaining the best operating efficiency t with the operation of the works which it serves.

UTHOR. As Mr. Maccoun states, all large gas engines built untry are of the side crank type, as this design was insisted the steel works' engineers, and it cannot be denied that the k design proved to be very satisfactory and has many advan- r the center crank construction, but it should not be over- at it makes American gas engines considerably heavier and ensive than European engines, which are without exception h center cranks.

ling the question of governing gas engines, the governing nt mixture is decidedly favored by American engine builders, pears that this system gives more satisfactory results in our than the so-called constant-compression-stratification method ning.

ot agree with Mr. Maccoun that it is of such great impor- use some particular brand of cylinder oil for lubricating gas- ylinders. At the plant under discussion very excellent re being obtained by the use of standard gas engine oil, s about the following characteristics:

osity liabue	Flash point deg. fahr.	Fire point deg. fahr.	Spec. Gravity
0.1	395	456	0.912

is considerably less expensive than the special heavy oils d by Mr. Maccoun, whereas the quantity consumed is not ch greater, so that the net result is a material economy in the brication. Frequent cylinder examinations have proved that of standard gas engine oil does not entail carbon deposits, e oil is burned up completely, leaving no residue in the ore or under the piston rings. This, in my experience, be said of the high-priced oils which, in order to obtain the h and fire points, must necessarily contain heavy hydro-car-

In regard to the amount of power obtainable from blast furnace gas, I think that the figure of 25 h.p. per ton of pig iron produced in 24 hours is pretty generally admitted to be a reliable basis for general calculations of the available power. It is true that this figure does not apply in every particular instance, and especially not in cases of plants having less than two or three blast furnaces. There are plants in existence, however, where practically no coal is burned under the boilers, and where all power requirements for the mills are being supplied by the excess gas from the blast furnaces. The Gary works of the Illinois Steel Company exemplify this statement.

Mr. Maccoun is perfectly correct in maintaining that the gas engine is not the universal panacea for the needs of a blast furnace plant. In isolated plants, for instance, where a large proportion of the gas produced by the furnaces must go to waste simply because there is no field for its utilization, and where the gas is therefore of no value, the installation of costly gas engines may be uneconomical and undesirable. In other plants there may be old steam engines in operation which are running so satisfactorily, though not economically, that they may render good service for years to come. In such cases it would be a waste of money to discard these engines and to replace them by gas engines, since the low-pressure steam turbine is available to improve materially the thermal efficiency of such plants.

In connection with the question which has aroused most of the discussion, namely the preliminary cleaning of blast furnace gas, it seems to be the unanimous opinion, brought out by Messrs. Morgan and Uehling, that it is obsolete practice to use raw blast furnace gas for any purposes about a blast furnace plant. It is generally recognized today that the gas for hot blast stoves and boilers should be cleaned to prevent the deleterious effect of the flue dust on the checker brickwork in the hot blast stoves and on the boiler flues. Opinions, however, are divided as to the degree to which blast furnace gas for these purposes should be cleaned, as well as to how this cleaning should be performed. According to the information obtainable on the subject at present, it does not seem possible to clean blast furnace gas by a dry process alone to such a degree of cleanliness as is claimed to be desirable in some of the discussions.

While it would seem consistent to assume that the benefit derived should increase proportionally with the degree of cleanliness of the gas, this is not so, since the ultimate economy is not only dependent upon the increased life of the checker work in the stoves, the high heats obtainable and the reduced labor of cleaning stoves and boiler

ues, but also to a very great extent upon the cost of installation, peration and maintenance of a gas-washing plant.

The discussion of this phase of the problem of gas cleaning ears out the general conviction that if blast furnace gas could be fficiently cleaned by a dry process only, such a cleaning plant could e installed, operated and maintained at a much lower cost than if et scrubbers, pumps, fans, etc., were necessary to accomplish the urpose in view. My opinion is that dry cleaning of the blast furace gas can be most effectively accomplished in an apparatus fulling the following three conditions:

a Reduction of temperature of the gas
b Sudden change of direction
c Sudden reduction of velocity

s explained in the body of the paper, a reduction of temperature of he gas can be accomplished without expense by the use of unlined as mains. Too much importance should not be attached to the dvantage of preserving the sensible heat of the gas, and calculaions at the plant under discussion have shown that the loss due to eduction to atmospheric temperature does not exceed 8%. On the ther hand any reduction in temperature of the gas is coincident with corresponding reduction of moisture, a very important factor in the conomical burning of the gas in stoves and under boilers.

The design of any effective dry cleaner should make it impossible or the dust to be stirred up after it is once deposited and this implies rovision for carrying off the separated flue dust in such a manner hat it is protected as much as possible from the effect of slips and he tendency of the gas current to entrain the dust particles. Any lry cleaners based on the action of centrifugal force are necessarily nuch more effective than the old type dust catchers, wherein the eparation of the dust occurred merely by the reduction of velocity n voluminous chambers. Granting the above requirements for an ffective dry cleaner, the horizontal dust separator described by Mr. Morgan must prove to be a very efficient dry cleaner.

At the plant under discussion a great deal of experimenting on a large scale was done in connection with this problem. As explained n the body of the paper, very voluminous dry dust catchers of the angential type were installed at all furnaces, but it was found that he efficiency was comparatively low.

A new development in the dry cleaning of gas is now being perfected at this plant, and it promises to solve the problem in a very simple, inexpensive and effective manner. This is the Brassert-Wit-

ting dry dust cleaner, for which letters patent are now pending. This dry cleaner combines in one apparatus the above named principles of successful dry cleaning, since it is unlined, makes use of centrifugal force, positive friction, reversal of direction and sudden expansion of the gas while protecting channels take the dust out of the path of the gases. These dust catchers are inexpensive and the operating cost is practically nothing, as they discharge the dust directly into railroad cars. The advantage of this system, aside from the low cost, is the fact that all the dust is recovered in a dry condition, doing away with the nuisance of sediment in sewers, river, etc. It has been shown in actual practice that one of these ten foot Brassert-Witting dry cleaners will take out about twice as much dust as a large 40-ft. dry dust catcher of the system preceding it, and with three of these cleaners in series, it is possible to obtain a cleanliness of less than one-half grain of dust per cu. ft.

With reference to S. K. Varnes' contribution on the question of wet gas cleaning, it is unquestionably true that this object can be satisfactorily accomplished in wet scrubbers other than the one described in the paper. Whether, however, such wet cleaners are more effective and cheaper in operation is yet to be proved. The four wet scrubbers in the plant under discussion, now operating in parallel, show an efficiency of over 90% for the last three months. The reduction of gas pressure to which Mr. Varnes refers is of no consequence since it does not exceed one inch of water column.

I cannot imagine a better distribution of water than that obtained in a tower filled with hurdles, since the water falling from hurdle to hurdle on its way from the top to the bottom of the wet scrubber is broken up again and again into a very fine mist so that practically every particle of gas must come into thorough contact with the water. I do not believe that the dust particles have to pierce a water film in order to be removed from the gas, but that the action which takes place in any type of scrubber consists in the wetting and weighing down of the dust particles by microscopical water drops in suspension.

The influence which impurities in the gas have on the cylinder wear can practically be disregarded if the engine gas is thoroughly cleaned in a modern cleaning plant. Conditions have changed materially in this respect in the last eight or ten years. Before adequate gas cleaning plants were in use the amount of impurities carried into the engines was so great that the dust and the lubricating oil formed a grinding material which caused the cylinders to wear out in a distress-

gly short time. Cylinder wear in modern blast furnace gas engines not primarily due to the dust, but to the material of the cylinders, ston ring design, lubrication, etc.

Mr. Stott mentioned that he has obtained with a combination reciprocating steam engines and low-pressure steam turbines, a ermal efficiency of over 21%. It is evident that Mr. Stott is refer- ng his thermal efficiency to the total amount of heat contained in the eam at the engine throttle and that he does not take into account the sses occurring by steam transmission between boiler house and gines, nor the efficiency of the boilers themselves and the losses in ie boiler house. Inasmuch as in a blast furnace plant the blast fur- ace gas is the available fuel, which in one case is used directly by mbustion in the gas engine cylinders and in the other case indirectly nder boilers for raising steam, a fair comparison of the efficiencies f these prime movers can be made only on the basis of the amount of eat units contained in the gas delivered at the gas cleaning plant i the former and at the steam boilers in the latter case. Assuming hat the combined losses in boilers and by steam transmission to he engines amounts to 35%, so that the combined efficiency of boilers nd steam pipe is 65%, the thermal efficiency of Mr. Stott's installa- ion would not exceed 13.7% compared with about 21% realized with our gas engines.

The latter figure, moreover, is not a value obtained by one or a series of individual tests, but is the average of the results obtained in actual commercial operation of the plant during the period of one year; nor is this figure in any way exceptional, as there are gas engine plants in existence abroad where average thermal efficiencies of 25% and more are being realized. There is no reason why with mechani- cally perfect engines of modern design these figures should not be duplicated and even exceeded in this country.

Mr. Coleman's discussion was submitted to Mr. C. J. Bacon, who states that the matter of which Mr. Coleman speaks, namely, accounting for losses in the venturi meter, was not included in the paper as there was no definite information available on the relative losses due to eddy currents, location or pressure holes, imperfect workmanship, etc. Mr. Bacon f ully agrees with all that Mr. Coleman says.

It is with particular pleasure that I refer to W. E. Snyder's remark- able contribution as one of the most valuable accounts of European gas-engine practice which has yet appeared in print and which will undoubtedly prove of great interest and value to the profession.

Having had experience in both European and American gas-engine practice and having actively witnessed the early development of the blast furnace gas engine here and abroad, I feel competent to endorse in every particular the views expressed by Mr. Snyder.

In preparing my paper I purposely refrained from broaching the subject of gas engine design and construction; nor did I yield to the temptation of relating my personal experience with gas engine operation here and abroad, well knowing that my reference to these subjects would have brought out a veritable avalanche of discussions on the part of both gas-engine builders and users. In line with this reasoning I do not care to take up point by point Mr. Snyder's remarks on the construction of certain gas engine parts, but I wish to elaborate a little on one statement which is in line with the subject matter of my paper.

It is an established fact that all gas cleaning plants installed in this country within the last five years have been very successful and practically free from trouble. This is largely, if not exclusively, due to the foresight of American steel works managers, who recognized that in view of what had been done in Europe along this line any attempts to solve the problem by carrying on lengthy and costly experiments would have meant wasting money and retracing the steps which their European colleagues had taken before. Instead they willingly took advantage of the experience of others and adopted European methods and apparatus, perfecting them to meet their own conditions. It is equally true that many of the difficulties encountered in the operation of our gas engines in this country would have been avoided if this principle of profiting by the experience of others had been more closely adhered to in designing and building American gas engines.

It is very gratifying to note the close coincidence of the results obtained in American and European operating practice, especially in regard to the purification of blast furnace gas and the lubrication of gas cylinders.

No. 1282

'HE MECHANICAL ENGINEER AND THE TEXTILE INDUSTRY

By H. L. Gantt, New York
Member of the Society

: textile industry enjoys the distinction, to a greater extent, ps, than any other, of having been brought to a high state of per- n without the aid of the mechanical engineer. The machinery leveloped by the mechanic before the mechanical engineer ıe a very important factor in the industrial world, and the plants and are still, built by mill architects, who as their name implies chitects rather than engineers. The most important field of this try that the engineer has entered is the power department, and is field he has done much good work. The complicated and ıte machines for working cotton fiber, however, which are ers of mechanical skill, have been brought to their high state of ction by men who were mechanics rather than mechanical engi- . The operation of these machines, until recently, has been ted by men whose training was exclusively that of the factory, who could solve well a concrete problem.

In this industry there is, as a rule, a wider gap between the ıcial interests that control, and the "help" that operate, than : is in almost any other industry.

The textile schools are today doing much to fill this gap by ılying to the mills educated men who, while understanding the il operation of the machines, are capable of comprehending the er problems of management, and can thus form a link between financial men that control and the mechanics that operate.

The lack of such men in the past is undoubtedly responsible the fact that some of the processes which influence the subject management more than they do the product, and which are ily susceptible of being standardized and done automatically, are

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still being done expensively and inefficiently by hand, and in a manner that causes much subsequent labor and expense that should be avoided. The solution of this problem belongs more particularly to the function of management, for the workman often does not see the influence of one process on a subsequent one in another department.

5 I refer, for example, to the process of handling cloth in a bleachery. In order to make clear the point in mind, it is necessary to explain that in the process of bleaching, cotton cloth is generally sewed together piece by piece and handled in the form of a rope, which is drawn from one operation to the next by means of rolls. This rope of cloth is subjected to the action of various liquids, being first boiled in an alkali and then washed. After being washed it is usually impregnated with acid (technically "soured"), and allowed to stand in a pile for some minutes to allow the acid to act. The methods of forming this pile and of withdrawing the cloth from the pile, are the operations to which I have special reference.

6 As the piling operation is repeated after each of several impregnating operations, the successive pilings divide the process into a series of separate and distinct stages with a loss of time between every two. The usual method of piling is as follows:

7 The cloth is drawn from the souring machine by an overhead roll, which drops it to the floor beneath. A boy stands on the pile of cloth and so guides it with a stick that it is piled in substantially uniform horizontal layers. When the pile has reached a size determined by the judgment of the bleacher (or the boy), the rope of cloth is broken at a seam and a second pile is formed. When in the judgment of the bleacher the first pile has stood long enough, the cloth is withdrawn and pulled through a washing machine into a bath of chlorine water (technically "chemic"), after which it is again piled in the same manner by a boy with a stick. The judgment of the bleacher as to the time cloth should lie in a pile after impregnation seems to be controlled by his temperament, or by tradition, rather than by knowledge, for we find that hardly any two bleachers have the same opinion as to how long the cloth should be subjected to the action of the acid; and the practice varies from a few minutes to twenty-four hours. As a matter of fact the acid does all its work in ten minutes or less, and no beneficial effect can be discovered by a longer treatment.

8 Inasmuch as it is necessary to pull the cloth from the top of a pile, the leading portion as it leaves the sour pile has been acted

ı by the acid a shorter time than that at the bottom of the

The top of the second pile is attached to the bottom strand of first pile, and the top of the third pile is attached to the bottom he second.

) As each strand of cloth usually goes through several pilings in course of being bleached, the action of the bleaching liquors on portion of the cloth would be alternately long and short, accord- as that portion of the cloth was at the bottom or the top of a pile. ıe rope of cloth was always broken in the same place, the worst ; could happen would be an unevenness in the bleach due to the :rence in treatment. It frequently happens, however (and this ore often the case than not), that the rope of cloth is not broken in same place; and when this occurs the various lots of cloth of which rope is composed, which usually belong to different customers ome almost hopelessly mixed. The expense of straightening out h a mix-up has usually been considered one of the legitimate ex- ses of bleaching. Add to this the fact that the piling boy often s the cloth so carelessly that it tangles as it is pulled off the pile, not only damages itself, but usually shuts down a portion of plant for awhile.

1 If we also realize the fact that chlorine, or "chemic," not only ns a most unpleasant atmosphere to work in, but is actually injur- ı to the lungs, it would seem that some automatic piling machine ch would hold the required amount of cloth and permit the lead- end of the pile to be withdrawn would long ago have been devised. smuch, however, as this is not a problem requiring great mechani- skill, but one requiring a somewhat different kind of knowledge, pparently had never been attacked until the writer came in con- t with it.

2 Fig. 1 shows the machine which has been developed to accom- h the result, and Fig. 2 shows the cloth as it is delivered to and hdrawn from the machine. The machine consists of an inclined te, with upturned ends, and having a bottom composed of a series ndependent rollers, freely revolving. The cloth is dropped into tall stack, and falling on the rollers is carried by its own weight the bottom of the incline. The incline is filled, and as the fabric s in the receiving stack, the forward end of the pile is forced upward he other end of the machine, from which it is pulled off at the rate which it enters the receiving stack.

3 By making the chute of the proper length a pile of cloth of any e may be held, and the cloth may be subjected to the action of the

impregnating liquor for any desired time, all portions of the fabric receiving exactly the same treatment. Such action produces uni-

FIG. 1 AUTOMATIC PILING MACHINE

formity of bleach impossible under the old conditions, and as the is no need for breaking seams, the goods go through the bleach hou in the order they went in, which produces a saving of expense as

realized only by the man who has operated under both
ls. The straightening out of "mix-ups" and the "closing
"short lots" are the bane of a finisher's existence, and any-
hat reduces these troubles does much, not only to smooth
eration of the works, but to assure the customer that he is

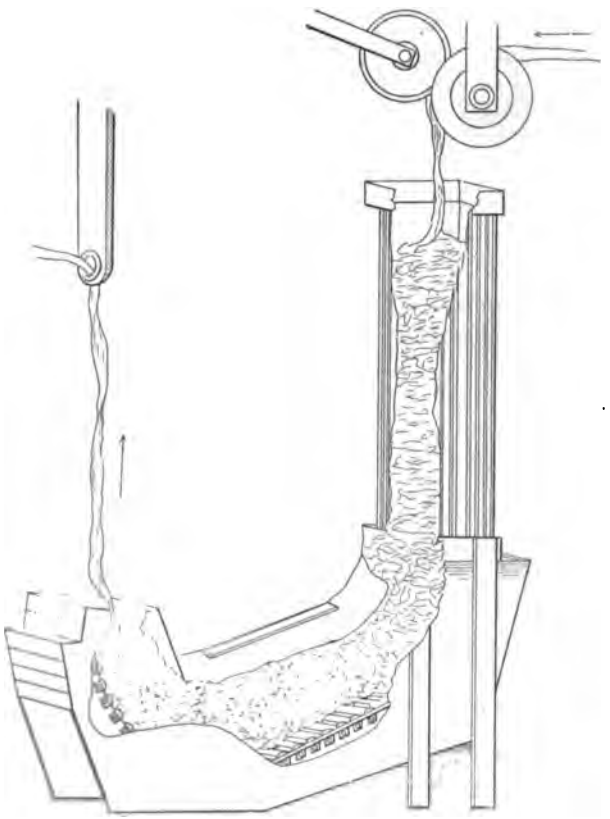

FIG. 2 PROGRESS OF CLOTH THROUGH MACHINE

g back exactly the goods he sent. Moreover the dirt and
ge caused by the piling boys are eliminated.

The saving in always having clean goods in uniform condition
ater than the saving in wages of the boys, and the relief to the fore-
of having a smaller number of bleach-house boys to manage,
it possible for him to devote his time to bleaching rather than
ys, with distinctly beneficial results to the bleaching.

15 In addition to the advantages already mentioned, there is a marked saving in time, for the cloth remains subject to the action of each liquid only the time needed to produce the desired result. Each piling machine takes the place of from three to four bins, and as it takes up less space than one bin, the saving in buildings is very con

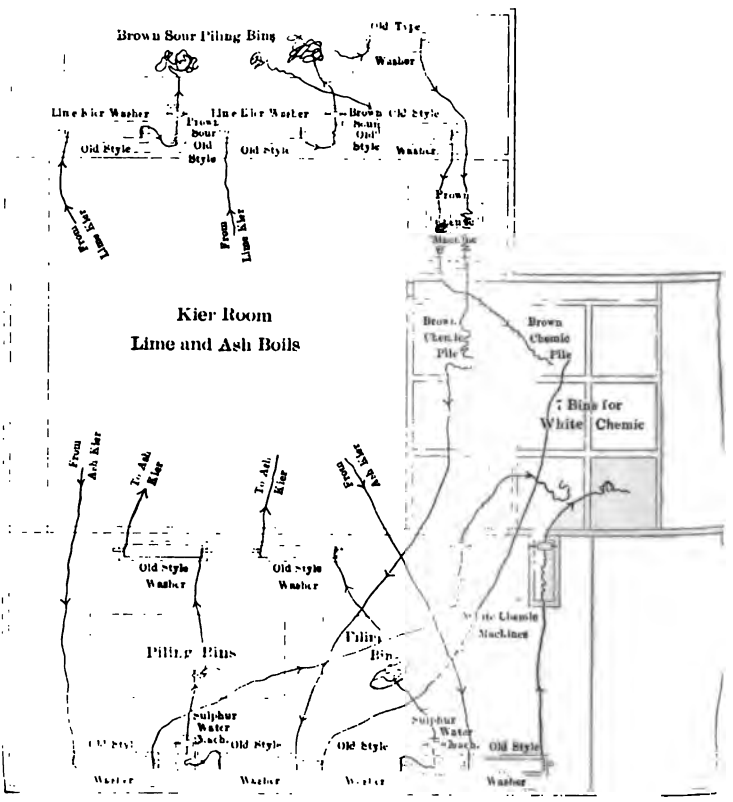

FIG. 3 ARRANGEMENT OF BLEACHERY (OLD SYSTEM)

siderable. In one case, when the washing, "souring" and "ch machines were rearranged in such a manner as to use a full equipm of piling machines to the best advantage, the saving in bleach-h space amounted to more than 40 per cent. Wherever the mach have once been installed it is obvious that they soon become dispensable.

16 The fact that such an important operation can be taken ca in such a simple manner, is the best evidence that the writer ent

ld that has not been thoroughly investigated by the mechanical neer. The field is still open, for plants are being built today to lle cloth exactly as it has been handled for fifty years. The lers of these plants have not yet discovered the function of the hanical engineer, and are still putting their faith exclusively in chers.

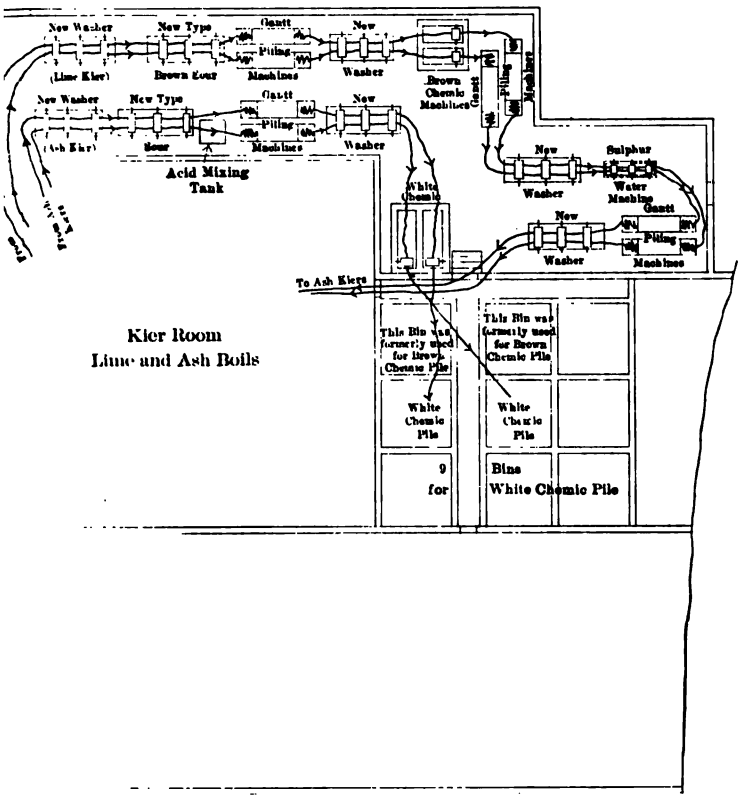

FIG. 4 ARRANGEMENT OF BLEACHERY (NEW SYSTEM)

17 Fig. 3 represents the course of cloth through a bleachery where e writer was told that the process had not been changed for fifty ars. Fig. 4 shows the course of the cloth in the same bleachery ter it had been equipped with piling machines, and other machines lapted to work economically with them. The new installation kes up less than 60 per cent of the space of the old and is operated y six people against the twenty people formerly needed.

18 The operations and their sequence are the same in the new as in the old layout, except for the installation of an additional "sour", which was thought desirable to remove the alkali of the second boil. The "new layout" is not a new method of bleaching, but simply a mechanical engineer's method of handling the old. There is hardly a bleachery in the country where the mechanical engineer cannot do similar work, and that without doing violence to the prejudices of the bleacher.

19 The standardization of bleaching methods must come later, and will take time, for we have here the habits of at least half a century to combat.

20 Thefield of the mechanical engineer today seems to be industrial. He is needed in all kinds of industries. Up to this time his attention has been confined largely to the power portion, and almost exclusively to the metal working portion of our industry.

21 By accident, having always been engaged in the metal working industry until a few years ago, I got into the textile industry, and am also familiar with some other industries, and I am satisfied that the field for the mechanical engineer in the non-metal working industries is as large, if not far larger than in the metal working industries, since the latter have been developed to a much higher state of perfection than the former.

22 At a meeting of the National Metal Trades Association in New York at which I was present, statistics were given as to the decreasing cost of production of machines of various kinds. Those in attendance were largely engineers and manufacturers, whose business it is to manufacture cheaply, and who were interested in effecting shop economies. Shortly afterwards I read a paper in Boston before the National Association of Cotton Manufacturers and there I found comparatively few people who were familiar with the details of their shop. They were more skilful as merchants, for the high price of their raw materials, cotton, for instance, was such as to make the buying and selling end of their business much more important in their eyes than the actual process of manufacturing. The best talent was devoted to the buying and selling end and they knew but little about the details of manufacture in many cases.

23 Until the average cotton mill owner comes to the conclusion that something more is needed to make a manufacturer than a classical education, this situation will continue. The value of the mechanical engineer in this field has not yet been realized.

No. 1283

THE ELASTIC LIMIT OF MANGANESE AND OTHER BRONZES

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Member of the Society

To keep up with the demands upon the laboratory for more work in a given time, testing machines have been speeded up and the slow extensometer has largely been displaced by the dividers, used either unchanged or with some means of magnification. To represent castings and forgings the short test piece with one-half inch diameter and two-inch gage length is almost universal. As a consequence, while reports of tests usually include a statement of "elastic limit," the property of the material actually determined is in reality that more or less vague value called the yield point. It is the object of this paper to show that while the yield point for steel is so well marked in properly conducted tests, and bears a sufficiently definite relation to the true elastic limit to warrant the dependence placed upon it by the engineer, there is no equally well-defined point found in testing bronzes, and the value commonly obtained from rapid commercial tests as the elastic limit or yield point on bronze may be quite misleading.

2 Manganese bronze was selected as the metal to be subjected to the series of tests here recorded because, of the modern alloys, it is one of the strongest and is readily obtainable in the market. It is not proposed, however, to discuss at length the properties of manganese bronze as such. This metal is used as a type and the results, so far as behavior under a tensile test is concerned, may be taken as typical of brasses and bronzes in general, at least so far as they have come under the observation of the author in some seventeen years of testing materials.

3 Specifications issued by the Navy Department, March 30, 1909,

Presented at the Spring Meeting, Atlantic City 1910, of The American Society of Mechanical Engineers.

for manganese bronze, required the following approximate composition:

Copper	52 per cent
Iron	1 per cent
Zinc	46 per cent
Tin	1 per cent
Manganese	Trace
Aluminum	0.5 per cent

The specification further required:

Tensile Strength	65,000 lb. per sq. in.
Elastic Limit	30,000 lb. per sq. in.
Elongation	15 per cent in 2 in.
Reduction of area	25 per cent

They state "the elastic limit is to be the yield point, measured by the drop of the bar."

4 Manganese bronze castings in the form of cylindrical bars about 1½ in. in diameter by 24 in. long, were ordered from several foundries supplying this alloy; the orders were placed through the regular channels, bars of about this size being required in ordinary production. In this way it was hoped that commercial material would be obtained, such as might be expected in castings of more intricate shape. The results on these specimens, ordered without reference to intended use, checked very well with those upon samples submitted previously by the same individuals, especially for the purpose of showing the qualities of their material. To indicate the effect of working upon the metal, there were also ordered two bars of the same dimensions hot-rolled to size, and two bars hot-rolled and cold-drawn. The effect of the cold drawing was lost to a great extent by the necessary turning off of the surface in preparing the specimen for test. Much of the cold-drawn metal is used in this way, however, when screw threads are required to provide means of fastening the part in place in the structure. From the bars so obtained, specimens were turned which provided a test section 1 in. in diameter by 8 in. between gage marks, and which had, for the purpose of gripping, ends 1½ in. in diameter threaded to fit the nuts required by the testing machine.

5 Some of these specimens were pulled in the laboratory of the General Electric Company at Schenectady, some in the testing machine at the United States Arsenal at Watertown, and others in the laboratory of the Halcomb Steel Company at Syracuse. The tests

Ialcomb laboratory were made to obtain autographic strain
s; the other tests were made with an extensometer.

the tests with the extensometer, after the instrument had
ıced, an initial load of 1000 or 2000 lb. per sq. in. was applied
first reading taken; readings were then obtained at successive

TABLE 1 CAST MANGANESE BRONZE, MARK 9902 B

EXTENSOMETER TEST

Original diameter, 0.9995 in. Original length, 8 in.

STRESS	EXTENSOMETER READINGS		MEAN DIFFERENCE	STRAIN	
Per Sq. In.	Right	Left		Total	Unit
			Initial Reading		
2,000	0.0235	0.0075			
4,000	0.0245	0.0089	0.00120	0.0012	0.00015
6,000	0.0254	0.0107	0.00135	0.00255	0.00032
8,000	0.0263	0.0122	0.00120	0.00375	0.00047
10,000	0.0272	0.0136	0.00115	0.00490	0.00061
12,000	0.0282	0.0151	0.00125	0.00615	0.00077
14,000	0.0293	0.0165	0.00125	0.00740	0.00092
16,000	0.0306	0.0181	0.00145	0.00885	0 00111
18,000	0.0320	0.0198	0.00155	0.01040	0.00130
20,000	0.0342	0.0219	0.00215	0.01255	0.00157
22,000	0.0370	0.0246	0.00275	0.01530	0.00191
24,000	0.0414	0.0279	0 00385	0.01915	0.00239
26,000	0.0456	0.0321	0.00420	0.02335	0.00292
67,600	Tensile Strength				

iameter..... 0.695 in.	Elongation.....27.5 per cent
of area. .....51.6 per cent	Elastic limit (from curve) 15,000 lb. per sq. in.
ır test.....10.20 in.	Modulus of elasticity 12,900,000 lb. per sq. in.

COMMERCIAL TEST

ımeter..... 0.503 in.	Reduction of area.....40.8 per cent
ıgth..... 2 in.	Elongation.....32.5 per cent
iameter ..... 0.387 in.	Rapid stretch (yield point).26,000 lb. per sq. in.
ır test..... 2 65 in.	Tensile strength.....69,650 lb. per sq. in

ɔplied in equal steps. In some cases, the readings were con-
·egularly until the increase in extension per increment of load
great that there was no doubt that the strain diagram had
d markedly from the straight line demanded by Hooke's law;
: tests, the normal succession of readings was continued only

TABLE 2 CAST MANGANESE BRONZE, MARK 9002 A

EXTENSOMETER TEST

Original diameter 0.995 ft. Original length 8 in.

Stress		Extensometer Readings		Mean Difference	Strain	
Actual	Per Sq. In.	Right	Left		Total	U
					Initial Reading	
1,570	2,000	0.0255	0.0125			
3,140	4,000	0.0270	0.0133	0.00115	0.00115	0.
4,710	6,000	0.0282	0.0147	0.00130	0.00245	0.
6,275	8,000	0.0290	0.0163	0.00120	0.00365	0.
7,848	10,000	0.0298	0.0179	0.00120	0.00485	0.
9,415	12,000	0.0307	0.0194	0.00120	0.00605	0.
10,985	14,000	0.0318	0.0208	0.00125	0.00730	0.
12,555	16,000	0.0328	0.0223	0.00125	0.00855	0.
14,120	18,000	0.0342	0.0239	0.00150	0.01005	0.
1,570	2,000	0.0264	0.0122	0.0008	set	.....
14,120	18,000	0.0345	0.0232	.....	.....	.....
15,690	20,000	0.0360	0.0253	0.00180	0.01185	0.
1,570	2,000	0.0270	0.0125	0.00075	set	
15,690	20,000	0.0365	0.0250	.....	.....	.....
17,260	2,2000	0.0384	0.0273	0.00210	0.01395	0.
18,830	24,000	0.0412	0.0301	0.00280	0.01675	0.
1,570	2,000	0.0291	0.0140	0.00265	set	.....
18,830	24.000	0.0418	0.0296	.....	.....	.....
20,400	26,000	0.0446	0.0332	0.00320	0.01995	0.
53,480	68.160	Tensile Strength				

Reduced diameter ..... 0.717 in.
Reduction of area ..... 48.5 per cent
Length after test ..... 10.22 in.
Elongation ..... 27.8 per cent
Elastic limit (from curve) ..... 16,000 lb. per sq. in.
Modulus of elasticity ..... 13,000,000 lb. per sq. in.

COMMERCIAL TEST

Original diameter ..... 0.5026 in.
Original length ..... 2 in.
Reduced diameter ..... 0.338 in.
Length after test ..... 2.84 in.
Reduction of area ..... 54.8 per cent
Elongation ..... 42.0 per cent
Rapid stretch (yield point) ..... 35,000 lb. per sq. in.
Tensile strength ..... 67,940 lb. per sq. in.

til the first positive increase in extension per increment of load was ted, when the stress was reduced to the initial load for the measure- ent of permanent set, after which the load was returned to the value st left. a new reading taken and the test continued with further terminations of set at intervals. The values of stress and correspond- g strain obtained were plotted, and the elastic limit recorded as the ess at the point of inflexion of the curve drawn through the points. 7 The specimens subjected to these tests were about 12 in. long er all. From the remainder of the 24-in. bars, the usual $\frac{1}{2}$ in. by 2

TABLE 3 EXTENSOMETER AND COMMERCIAL TESTS

EXTENSOMETER TESTS: ALL SPECIMENS 1 IN. (APPROXIMATE) DIA. BY 8 IN. LONG

Mark	9908B	Q2992A	Q2992B	Q6434A
mple	Cast	Hot-Rolled	Hot-Rolled	Cold-Drawn
duction of area, per cent	14.1	53.2	53.2	53.3
ngation, per cent	6.25	33.5	33.75	31.0
stic limit, lb. per sq. in	19,400	18,000	18,000	17,000
mile strength, lb. per sq. in	62,070	71,800	71,640	71,620
dulus of elasticity, lb. per sq. in	13,810,000	13,000,000	13,810,000	12,800,000

COMMERCIAL TESTS: ALL SPECIMENS 0.5 IN. (APPROXIMATE) DIA. BY 2 IN. LONG

mple	Cast	Hot-Rolled	Hot-Rolled	Cold-Drawn
duction of area, per cent	23.5	44.9	45.9	39.9
ngation, per cent	26.5	37.5	36.5	34.0
ld point (rapid stretch), lb. per sq. in.	29,000	30,000	30,000	43,000
mile strength, lb. per sq. in	80,420	74,780	74,480	74,260

Bar 9908B was unsound, hence $\frac{1}{2}$ in. by 2 in. test was turned from side of bar, instead of center. nsoundness due to oxidation and perhaps segregation, probably accounts for the apparent cold rittess of the 1 in. by 8 in. test piece. Fracture occurred in a flaw, while many incipient fractures cracks were noted in surface before final rupture.

n. test pieces were turned and tested in the customary commercial ray, using a pair of multiplying dividers to indicate the point of ncrease in rate of stretch or yield point.

8 In Table 1 are given in detail a typical set of readings taken in test at regularly increasing loads, together with the results of the ommercial test upon the specimen from the same bar. In Table 2, imilar data are given from a test with measurements of set. Table shows the results obtained upon the other specimens tested at Sche- ectady. The curves for all these tests are assembled on Fig. 1. Details of the tests at the Watertown Arsenal are stated in Tables 4

and 5, and the curves from these data are given on Fig. 2. The results of the work at the Halcomb laboratory are shown in Table 6 and Fig. 3; the scale of the diagram is so small that the location of the point of inflexion is uncertain within about 2000 lb. actual load, and the values in the tables are placed rather high. The multiplying dividers used in the commercial tests here recorded magnify the movement of the gage marks about ten times, and are a much more sensitive instrument than the machinists' dividers for locating the yield point; hence, the yield points recorded are lower than are usually reported.

9 In the text books and elsewhere, the limit of elasticity is defined

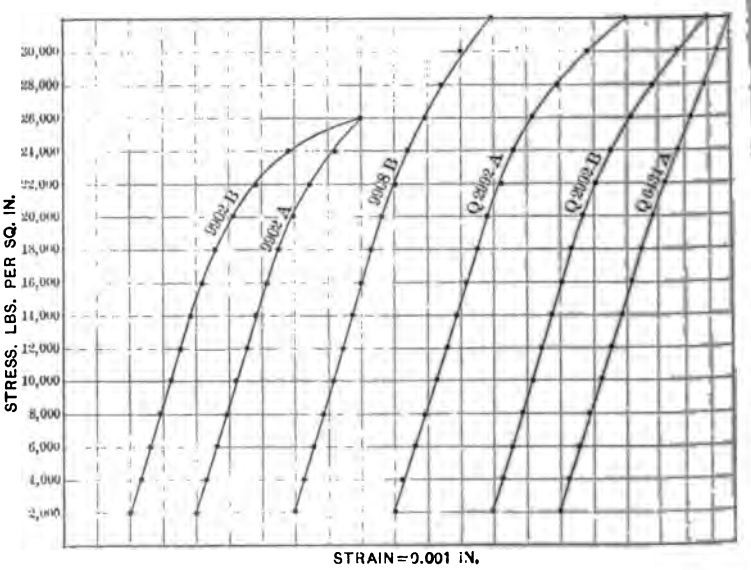


FIG. 1 CURVES PLOTTED FROM DATA IN TABLES 1, 2 AND 3

as that value of stress beyond which there is not full recovery of the initial dimensions or shape of the specimen after release of the load, or as the maximum stress that can be applied without producing permanent set. In other words, it is the value of stress beyond which Hooke's law no longer holds, and it is sometimes spoken of as the limit of proportionality of stress to strain.

10 Accepting this definition of elastic limit, it is seen that its value in the bronzes tested is from 16,000 lb. per sq. in. to 23,000 lb. per sq. in., whereas the yield points found for the cast metals ran from 25,000 lb. to 29,000 lb., and for the worked metals, from 30,000

TABLE 4 CAST MANGANESE BRONZE, MARK 9002 B

WATERTOWN ARSENAL TEST

Original diameter, 1.000 in. Original length, 8 in.

Stress	Reading	Difference	Strain		Set
Per Sq. In.			Total	Unit	
1000			Initial Reading		
2000	0.0006	0.0006	0.0006	0.00010	.....
3000	0.0013	0.0005	0.0013	0.00016	.....
4000	0.0020	0.0007	0.0020	0.00025	.....
5000	0.0027	0.0007	0.0027	0.00034	0
6000	0.0033	0.0006	0.0033	0.00041	.....
7000	0.0038	0.0005	0.0038	0.00048	.....
8000	0.0044	0.0005	0.0044	0.00055	.....
9000	0.0051	0.0007	0.0051	0.00064	.....
10000	0.0060	0.0009	0.0060	0.00075	0
11000	0.0067	0.0007	0.0067	0.00084	.....
12000	0.0075	0.0008	0.0075	0.00094	.....
13000	0.0080	0.0005	0.0080	0.00100	.....
14000	0.0086	0.0006	0.0086	0.00108	.....
15000	0 0090	0.0004	0.0090	0.00113	0
16000	0.0105	0.0015	0.0105	0.00131	.....
17000	0.0119	0.0014	0.0119	0.00149	0.0005
18000	0.0133	0.0014	0.0133	0.00166	.....
19000	0.0145	0.0012	0.0145	0.00181	.....
20000	0.0167	0.0022	0.0167	0.00209	0.0025
25000	0.0280	0.0113	0 0280	0.00350	0.0065
30000	0.0487	0.0207	0.0487	0.00609	0.0241
40000	0.2090	0.1603	0.2090	0.02613	0.1730
64458	Tensile Strength				

iameter..... 0.70 in.
r test .....10.53 in.
of area.....51.0 per cent
.....31.6 per cent
it.....16,000 lb. per sq. in.
elasticity.....12,390,000 lb. per sq. in.

COMMERCIAL TEST (MADE AT SCHENECTADY)

ameter.....0.503 in.
gth.....2 in.
ameter.....0.387 in.
r test.....2.65 in.
of area.....40.8 per cent
.....32 5 per cent
sh (yield point) .....36,000 lb. per sq. in.
ngth.....69,650 lb. per sq. in.

TABLE 5 CAST MANGANESE BRONZE, MARK 9908 B

WATERTOWN ARSENAL TESTS

Original diameter, 0.7854 in. Original length, 8 in.

STRESS		READING	DIFFERENCE	STRAIN		Set
Actual	Per Sq. In.			Total	Unit	
785	1000	0		Initial Reading		
1571	2000	0.0007	0.0007	0.0007	0.00009	.....
2356	3000	0.0013	0.0006	0.0013	0.00016	.....
3142	4000	0.0017	0.0004	0.0017	0.00021	.....
3927	5000	0.0023	0.0006	0.0023	0.00029	0
4712	6000	0.0028	0.0005	0.0028	0.00035	.....
5498	7000	0.0036	0.0008	0.0036	0.00045	.....
6283	8000	0.0040	0.0004	0.0040	0.00050	.....
7069	9000	0.0047	0.0007	0.0047	0.00059	.....
7854	10000	0.0052	0.0005	0.0052	0.00065	0
8639	11000	0.0059	0.0007	0.0059	0.00074	.....
9425	12000	0.0064	0.0005	0.0064	0.00080	.....
10210	13000	0.0070	0.0006	0.0070	0.00088	.....
10996	14000	0.0074	0.0004	0.0074	0.00093	.....
11781	15000	0.0081	0.0007	0.0081	0.00101	0
12566	16000	0.0088	0.0007	0.0088	0.00110	.....
13352	17000	0.0094	0.0006	0.0094	0.00118	.....
14137	18000	0.0099	0.0005	0.0099	0.00124	.....
14923	19000	0.0104	0.0005	0.0104	0.00130	.....
15708	20000	0.0113	0.0009	0.0113	0.00141	0.000
16493	21000	0.0120	0.0007	0.0120	0.00150	.....
17279	22000	0.0126	0.0006	0.0120	0.00158	.....
18064	23000	0.0135	0.0000	0.0135	0.00169	0.000
18850	24000	0.0143	0.0008	0.0143	0.00179	.....
19635	25000	0.0156	0.0013	0.0156	0.00195	0.000
20420	26000	0.0165	0.0009	0.0165	0.00206	.....
21206	27000	0.0171	0.0009	0.0171	0.00214	0.000
21991	28000	0.0185	0.0014	0.0185	0.00231	.....
22777	29000	0.0200	0.0015	0.0200	0.00250	.....
23562	30000	0.0210	0.0010	0.0210	0.00263	0.000
27489	35000	0.0325	0.0115	0.0326	0.00408	0.000
31416	40000	0.0607	0.0282	0.0607	0.00759	0.000
35343	45000	0.1225	0.0618	0.1225	0.01531	0.000
53900	68662	Tensile Strength				

Reduced diameter..... 0.91 in. Elongation..... 10.0 per cent
Length after test..... 8.85 in. Elastic limit..... 23,000 lb. per sq
Reduction of area ..... 17.2 per cent Modulus of elasticity, 13,200,000 lb. per sq

COMMERCIAL TEST (MADE AT SCHENECTADY)

Original diameter..... 0.504 in. Length after test..... 2.58 in.
Original length..... 2 in. Elongation..... 26.5 per cent
Reduced diameter..... 0.426 in. Rapid stretch (yield point) 29,000 lb. per sq
Tensile strength..... 80,420 lb. per sq. in.

4,000 lb. per sq. in. Had ordinary dividers been used, the val- the cast metals would have been placed between 30,000 lb. 000 lb. per sq. in. The strain diagrams from the extensometer ıow the general shape of the elastic curve of the metal, and the accurate fixing of the point of inflexion of the curve; the ıphic diagrams however, show not only the actual shape of the but also why there is the uncertainty in the locating of the oint or point of rapid increase in rate of stretching.

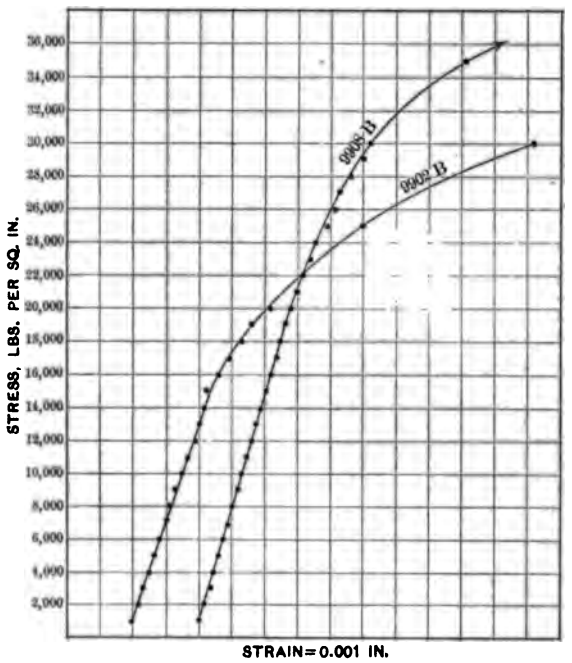


FIG. 2 CURVES PLOTTED FROM DATA IN TABLES 4 AND 5

For comparison, the autographic diagram of a piece of com- "structural medium" steel is shown as No. 1 in Fig. 3. At le of the diagram, no inflection of the curve is seen until it ly breaks sharply, actually drops and remains practically ıtal until it finally picks up again. This jog is entirely char- ic of mild steel, and is found to a more or less marked extent eels, save perhaps the very hard varieties. There is, however, ık of any sort in the curves obtained from bronze; they are smooth. Somewhere along the knee of the curve, the tester

notes that the material is stretching faster; just where he notices it will depend upon the sensitiveness of the means employed to indicate stretch, and upon his skill and sharpness in observation. The jog in the steel curve is indicated simultaneously by the slipping of the dividers and by the dropping of the scale beam of the testing machine driven at constant speed. The scale beam does not drop when testing bronze; the operator finds the poise gradually traveling more

TABLE 6 HALCOMB STEEL COMPANY TESTS

AUTOGRAPHIC TESTS, ALL SPECIMENS 1-IN. (APPROXIMATE) DIA. BY 8-IN. LONG

Mark		9902A	9908A	Q2902A	Q[illegible]A
Number on curve sheet	1	2	3	4	5
Sample	Steel	Cast	Cast	Hot-Rolled	Cold-Drawn
Reduction of area, per cent	53.6	8.3	14.1	53.3	38.9
Elongation, per cent	36.3	27.2	6.6	34.4	25.2
Elastic limit, lb. per sq. in.	38,000	21,400	22,900	22,800	35,[illegible]
Tensile strength, lb. per sq. in.	60,140	69,700	63,940	71,320	68,[illegible]

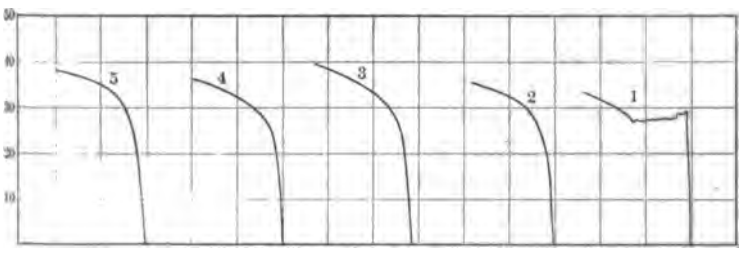
COMMERCIAL TESTS (MADE AT SCHENECTADY): ALL SPECIMENS 0.5 IN. DIA. BY 2 IN. LONG

Sample	Cast	Cast	Hot-Rolled	Cold-Drawn
Reduction of area, per cent	54.8	22.4	44.9	39.3
Elongation, per cent	42.0	14.5	37.5	34.0
Yield point, lb. per sq. in.	25,000	26,000	30,000	44,[illegible]
Tensile strength, lb. per sq. in.	67,940	70,900	74,780	74,[illegible]

slowly to maintain balance, but who can say when the change in rate began?

12 It is customary to find the yield point in mild steels, and in fact, in annealed steels generally, at about 50 per cent of the maximum strength. The yield point in mild steels corresponds, for all practical purposes, to the elastic limit. As the steel becomes harder, due to increase in carbon or the addition of alloying metals, or to heat treatment, the yield point rises rather more rapidly than the elastic limit, although the difference between the two is not so great but that the former may be used in calculations, and the yield point itself is less sharply marked, though still observable if sufficient care is taken. The yield point in steel is accepted as a safe guide to the engineer, in deciding upon the maximum stresses that may safely be permitted in parts designed to carry load.

3 That no such dependence can be placed upon the so-called yield nt, as it is determined upon bronzes, is evident; rather, recourse st be had to the slower but more accurate determination of the e elastic limit if safe data are desired. It is especially noteworthy it the sets found at the minimum values of yield point as usually orted are a very considerable proportion of the total stretch that s taken place in the metal at those stresses, and that sets are found stresses which are but 40 to 50 per cent of these reported yield ints. Under certain conditions of dead load, a stress of 75 per cent the elastic limit is sometimes considered at least not unsafe; if such oad were calculated for bronze, upon the basis of the usual commer- l test for yield point, instability of the part so designed would be evitable.



IG. 3 AUTOGRAPHIC STRAIN DIAGRAMS TO ACCOMPANY DATA IN TABLE 6

14 Hot working of the metal has not materially improved its stic properties, but has greatly increased its toughness, and prob- ly in an extended series of tests, would have been found to impart iformity. It is well known that this particular alloy is relatively fficult to handle in the foundry because of its sensitiveness to tem- rature of pouring and to changes in composition, at least in the nse of impurities in the constituent metals, and because of its great rinkage, requiring large feeders and sink heads. As in other copper loys, many of the ill effects of this sensitiveness may be largely over- me by hot working. The data here presented are too meager to arrant lengthy discussion of the effects of cold working of the metal; is shown that in the case of bars of $1\frac{1}{2}$ in in diameter, the effects of e cold drawing may have largely disappeared when $\frac{1}{4}$ in. of metal is moved, except as shown in a lessened elongation. Neither hot nor ld working cause any change in the elastic curve of the metal; it mains a characteristically smooth curve. In other cold-drawn copper loys, when tested without removal of surface, the elastic curve

usually presents a much sharper bend at the knee than is found in the cast metal, or in the same metal when annealed; the same would probably be found with manganese bronze if tested as drawn, without turning. Cold-drawn metal, except wire, is seldom used without removal of the surface to provide means of fastening, and it surely is safer to test it as it is used rather than in the perhaps fictitious condition of strength due to skin hardness.

15 These results do not constitute a new discovery. In the literature of testing engineering, references may be found with direct bearing on the subject; but in these days of rapid progress and short-cut methods, much that is old, or that may be found only by search, is apt to be forgotten or overlooked. Comparatively few laboratories have autographic machines, and the use of the extensometer with a specimen only 2 in. long is not very satisfactory because of the small extension of so short a length of material under stress. Many otherwise well equipped laboratories have no extensometer. So much experience in testing materials is based upon work done upon iron and steel that it was perhaps a natural assumption that the characteristics of these metals would also be found in bronzes and similar alloys and hence that methods of testing used successfully with one would yield equally safe results when applied to the other. Test results which are misleading are exceedingly dangerous; they induce a false sense of security which may result in the failure of structures and lead to the condemnation of a material which would be perfectly satisfactory if properly applied and not unwittingly abused.

16 The author wishes to acknowledge the courtesy of Dr. John A. Mathews, operating manager, and Marcus T. Lothrop, metallurgical engineer, of the Halcomb Steel Company, in furnishing the means of obtaining the excellent autographic strain diagrams reproduced in Fig. 3.

DISCUSSION

S. A. Moss. Mr. Capp has pointed out that we cannot find the limit of proportionality in bronzes by the old steel method. I would like to ask, are we interested in the limit of proportionality at all? It seems to me that the engineer is interested in the permanent set, which may not be connected with the limit of proportionality in any way. It seems to me that it would be a good thing if we confined our attention to this set, and would in making tests on materials almost wholly remove the load after each application, measure the permanent set, apply a greater load, remove it almost wholly, and

ıeasure the permanent set, etc. In this way we could make a
f permanent set, and need not consider the stress-strain curve.
ırves are of the shape of the usual stress-strain curve, with
bend. The place where the bend begins could be defined as
ic limit, which is of much more interest to the engineer than
t of proportionality or the yield point.
cold-drawing process, or application of stress for a second
lds a complication. After material has once received a per-
set, it will not receive as great a one the second time. This
:aken into account and if desirable the place found where the
able permanent set begins after the second application of
This necessitates applying and removing each load twice
measuring the permanent set.

r. Dean asked if there was any evidence to show that a piece
left to itself for a time regained any of its original qualities.

Author. Mr. Howard at the Watertown Arsenal, has re-
repeated tests on bars which were overstrained a great many
go, and have since been laid aside to rest. The tests are not
completed, but there seems to be evidence that if the over-
not so great that the particles have been definitely torn apart
up in new arrangement, there will be almost an entirely
te recovery, in which the chances are that the original limit
ortionality will have been raised to a point between the original
nd that of the overstrain.
Moss's statement with respect to the location of what we
:all the first permanent set point is pertinent. It is perhaps
y coincidence that in most of the materials commonly tested
ineering purposes, the first permanent set point and the limit
ortionality very nearly coincide. Taking into account the very
ne it takes to conduct a test to determine the first permanent
nt and the difficulties in making sure that the lower load
l as the zero point is always exactly secured, there is a
ation for abandoning that method of test in favor of plotting
stic curve, and getting the limit of proportionality. The
are not so far apart that the engineer is not warranted in basing
e load on the limit of proportionality instead of on the first
ıent set point.
Moss had mentioned as possible a material which does not
ny permanent set until the stresses have been carried well out

on the curved portion of the elastic curve. Cast iron is apt to be such a material. There is practically no straight line portion on the elastic curve for cast iron, and yet it is difficult to measure any permanent set when testing, even the ultimate elongations being small and difficult to measure. Several persons have reported as much as $\frac{1}{4}$ per cent of elongation in 8 in., which is, of course, very little. The relatively more brittle metals usually test as high as 4 or 5 per cent, and tougher metals as high as 40 per cent.

A jog in the stress-strain curve is characteristic of all the mild or untreated steels, and it is also true that overstressing eliminates it. That is shown in testing cold-rolled steel or steel wire, the extreme case of cold-drawn steel. Steel wire is obtained by a controlled stressing of the material beyond its elastic limit by drawing it through a die, which to a certain extent controls the amount of the permanent set and of the overstressing.

The real object of testing is to determine the characteristics of a material so that one may decide what shall be safe stresses in any structure, taking into account the elastic properties of the material, its ability to stand up under repeated or alternating stresses and other similar conditions. Usually such safe loads are a certain proportion of the elastic limit. If, however, the elastic limit is determined by erroneous tests to be double its true value, any calculation based on such data is utterly unsafe.

No. 1284

THE HYDROSTATIC CHORD

ITH DISCUSSION OF ITS APPLICATION IN THE DESIGN OF LARGE PIPES OF REINFORCED CONCRETE

By Raymond D. Johnson,[1] Niagara Falls, N. Y.

Non-Member

The hydrostatic chord is allied to the catenary, the parabola and e circle, because all of these curves may be formed by a flexible extensible substance, supported at its two extremities and properly aded. If the load is uniformly distributed with respect to a hori- ntal line joining the supports, the action of gravity will shape the pporting substance to form a parabola. If the load is uniformly stributed with respect to the curve itself a catenary is the result. the load is applied by fluid pressure, irrespective of the direction gravity, so that the pressure is of uniform intensity normal to the rve, a circle is formed. If the load is applied by fluid pressure hich varies according to the head or depth of water at any point, ie curve resulting from this system of forces normal to the curve a hydrostatic chord, which can easily be imagined as the curve hich a flat canvas hammock would take if filled with water.

2 If the canvas were sewed together to form a closed curve, and pported on end as a vertical cylinder, the cross section would become rcular under fluid pressure. If now the open ends of the cylinder ere sealed with flexible bulkheads and the cylinder was tipped over n its side when completely filled with water the cross section would ecome a hydrostatic chord, although it would still theoretically e a circle also, until a drop of water was allowed to escape, that is, the water be regarded as incompressible. Since the shell of the ylinder is assumed inextensible, and a circle encloses the maximum rea for a given perimeter, it follows that the mere act of tipping such cylinder towards the horizontal position would immediately develop nfinite stress in the enclosing membrane, if the water could not par-

[1] Ontario Power Company, Niagara Falls, N. Y.

Presented at the Spring Meeting, Atlantic City, 1910, of The American ociety of Mechanical Engineers.

tially escape. If one now imagines a hole pricked in the side of the cylinder on top, and connected with a vertical pipe or piezometer, some of the water would escape up into the pipe and at the same time the shape of the cylinder would take on the characteristics of a true hydrostatic chord. The water would continue to rise until the head above the top was just sufficient to hold the remaining water in the equilibrium shape. At this time the surrounding membrane would be in pure tension, equal throughout, and of finite value. The very fact that the tension must be constant in all portions of the shell furnishes an easy means of constructing its shape, because the tension at any point is obviously measured by the product of the radius or curvature and the head at that point.

3 If more water now be poured into the piezometer pipe, the shape of the cylinder will approach a circle; its vertical diameter will lengthen and its horizontal diameter will shorten. It would, however, never become a circle for a finite head of water. Conversely, if water be drawn off, the shape would become more and more oblate until finally the membrane would collapse into a plane surface at zero head.

4 It seems apparent from the above discussion that a circle is not the natural shape for a pressure pipe lying on its side, especially if its diameter is large as compared with the water pressure. No one would think of designing a vertical water tank with an elliptical cross section, and thus subjecting the shell to enormous and unnecessary deforming stresses in its effort to become circular. And yet it has not been unusual, not only to design concrete pressure pipes circular, but even to go to the other extreme and shape the section with its least radius of curvature at the top instead of at the haunches.

5 This latter procedure might be compared to designing a stiff suspension bridge cable, say, for the sake of illustration, of reinforced concrete, and shaping it like an ellipse with its long axis horizontal, instead of the more natural shape in which the radius of curvature would decrease toward the center, instead of increasing. Such a chord is obviously so ridiculous that an example of it could not be found in practice. Instead it would probably be designed of parabolic shape, which would be perhaps as good a compromise as one could reach. If it were really too stiff to adjust its shape to changes of load, as for example when a moving load passed over the bridge, then more or less severe deforming stresses would be the result, but how much less than in the former case.

6 Similarly, although it is impossible to design a stiff pipe of

ıch a shape that there will be no deforming stresses under the vary-
g conditions of water pressure and back fill and the constant weight
: the shell itself, yet these stresses can be reduced to a minimum by
lopting a form which lies midway between the ideal equilibrium
ıapes which the pipe tries to assume under the various water pres-
ıres to which it may be subjected. This matter is of much prac-
ical importance in large conduits, proper design of the cross sec-
on meaning the saving of perhaps one-half the material, concrete
r steel.

7 It is not the writer's purpose to take up the mathematics of
he hydrostatic chord, nor to discuss the complications of a typical
esign. The element of judgment enters so largely into such a study
hat it is impossible to do it justice in restricted space and time.
\ few general hints may be of service.

8 It is well known that a circular cylindrical shell lying on its
ide has four nodes, or points of contra-flexure, due to its own weight.
Chese lie at points 50 deg. 36 min. 45 sec., and 146 deg. 19 min. 25
ec., respectively, from the vertical. It can be demonstrated that
he locations of the nodes due to the weight of the water within such
ı cylinder are the same. It can also be shown that the bending
noments due to both causes are exactly proportional at all points
ıf the arc, and may therefore easily be combined. The equilibrium
hape which would sustain the existing water pressure without any
endency to deform, can easily be plotted from the polar equation
ıf the bending moments in a circle, in terms of the angle of depar-
ure from the vertical, remembering that the radial intercept between
he circle and the new curve at any point, is a measure of the bending
noment at that point, and when multiplied by the corresponding
ension at that point of the circle will give the value of the bending
noment.

9 Conversely, if the bending moment be divided by the tension,
he radial intercept will be the quotient, and may be plotted. The
alue of this intercept at any angle, and for any assumed head H
bove the top of the pipe, is as follows:

$$\frac{r\,(\frac{1}{2} - y)}{H + r} - y$$

$$r$$

where r = radius of the circle, and $y = \frac{1}{2}\cos\phi + \frac{1}{2}\phi\sin\phi$.

10 Any number of such curves may be plotted, according to the
number of different values of H assumed, and all of these will of
course pass through the same node points.

11 These equilibrium shapes are not identical with the hydrostatic chord, for the reason that the forces acting to produce the latter are strictly normal to the curve itself, whereas in the former case the applied forces are always considered to be normal to the common circle for all the different equilibrium curves.

12 The discrepancy between the two curves for any given head is, however, so slight as to be negligible for all practical purposes. A measurable difference would scarcely be found except for very low heads, say less than one diameter above the top of the pipe, where the stresses are small and not important. After the head reaches

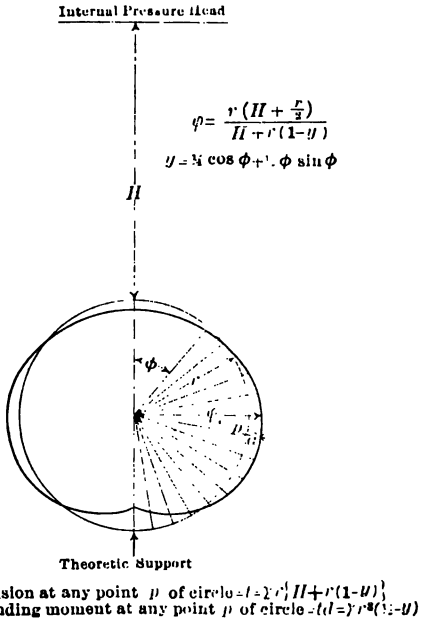


FIG 1 EQUILIBRIUM CURVE

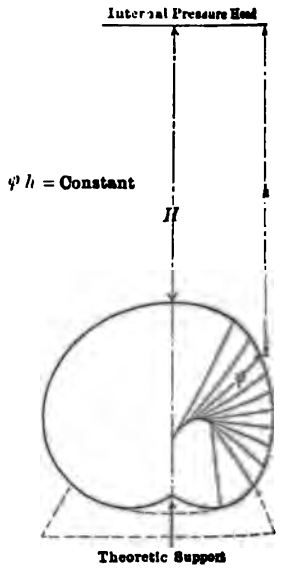


FIG. 2 HYDROSTATIC CHORD FOR SAME HEAD

a value of five or six diameters above the top of the pipe, the departure from a circular shape is comparatively slight, and therefore this discussion is particularly applicable only to large pipes under low pressure.

13 It will be found that when the pipe is supported on a continuous saddle, as is usually the case, the maximum stress is likely to be located at the top of the pipe, so that if the shell is made homogeneous no other point need be investigated for stress. If the pipe in-

l of being circular, is formed on the lines of any one of the equi-
um curves, or better still, on the lines of the true hydrostatic
d for a particular head, then the bending moments induced in it
ny other head may be scaled or computated at any point by
ng the length of the intercept between such a curve and the curve
esponding to the head under consideration. The value of the
ion at any point, which must be multiplied by this intercept, is
n by the formula $\alpha r [H + r (1 - y)]$, where α is the weight of
bic foot of water and the other quantities remain as before.

4 In arriving at the total stress it is necessary to combine alge-
cally the bending stresses due to weight of shell, back fill and
ght of water, and then add to them the tensile stress due to the
er pressure. The bending moments in a circle when lying on a
surface are simply expressed by the equation, $-\alpha r^3 (\frac{1}{2} - y)$.

5 When the pipe rests on a saddle the maximum stress is usually
nd at the top of the pipe, as before stated; and although its amount
omewhat lessened by the presence of the saddle underneath, it
ot considered advisable to rely on this, and it is best to design
stress at this point strictly as though the pipe had a very narrow
lle, or theoretically none at all.

6 The above reasoning is not to be regarded as hard and fast for
-book use, and the conclusions are known to be merely close ap-
ximations. Many interesting properties of the hydrostatic chord
e been studied by the writer, and much of the mechanics relating
pipe design has been more or less thoroughly worked out; but
re is so much of no practical application, and so much time would
needed to coördinate the material, that no attempt has here been
le to do so.

7 The curve itself is not new if one considers it the same as the
lrostatic arch with the stresses all reversed, but very little, if any,
dy of its properties and practical application has been published.
thing of the kind has ever come to the notice of the writer. As a
tter of theoretical mechanics and even of plane geometry there
ms to be an opportunity for a little addition to the technical in-
uction in those branches.

No. 1285

THE ENGINEER'S DUTY AS A CITIZEN

By Rear-Admiral Geo. W. Melville, U. S. N., Ret.

Honorary Member of the Society

ubtless everyone present has read Macaulay's famous chapter, s History of England, which describes the conditions obtaining 85. This chapter is one of the most wonderful descriptions in terature, giving as it does the details of every feature of the life at time, some 200 years ago. I refer to this account because I you to contrast it with the conditions of today, to which we are customed that it requires some effort to remember that the com- and conveniences of the poor man of today were beyond the wildest ms of the wealthiest men of the period described by Macaulay. hat time there were no sidewalks and the streets were unlighted; highways became bogs in rainy weather, and highway robbery almost a recognized profession; sanitation and sewerage were nown, and refuse heaps accumulated under the windows of the t and the wealthy; it was dangerous to go out alone at night; and s still legal to hang the unfortunate who stole a loaf of bread.

Macaulay remarks in one place that at such fashionable watering es as Bath, the nobility had to put up with accommodations at h the servants in the year 1850, in which he was writing, would turned up their noses.

Now when we compare the two periods and remember that there rdly a branch of human activity in which there has not been the test improvement, we are naturally led to ask to whom is the rovement due.

In all fairness, we should doubtless have to say that most of the essions have had a part in the amelioration of conditions, although student of history remembers with regret how the great lawyers osed the remission of the death penalty for what we would now ider minor offenses.

Physicians are undoubtedly entitled to much credit for ad- ces in medicine, surgery, sanitation and hygiene, and we might

ldress given at the Spring Meeting, Atlantic City 1910, of The American ety of Mechanical Engineers.

go on and give credit to others. It seems to me, however, that when some future Macaulay describes the condition of the United States at the beginning of the twentieth century and attempts to award the credit for the existing comforts and conveniences, the major part must be given to the profession of engineering. Within 100 years after the time described by Macaulay, Watt had so far perfected the steam engine as to bring about the beginnings of the factory system, making possible the low cost of clothing and of articles of manufacture of every kind. In a century the steamboat and the railroad had come into being. Then we have gas for illumination and the telegraph for rapid communication, and so on down the line to the present day with its electric light, electric railroad and telephone, every one due to the engineer.

6 Added to the superior facilities of communication by railroad and steamer came mechanical refrigeration, which enables the densely populated countries of the old world to be supplied with meats from the great plains of the new, and these superior means of transportation have provided the rapid movement of food products so that the whole world contributes to the delicacies of our table, no matter where we are.

7 The contrast between the conditions of the great cities of the period described by Macaulay with those of today is startling. Cities were without the conveniences which a country town of moderate size now considers absolute necessities. The systems of water distribution, sewerage, street paving, etc., are all the work of the engineer, and filtration plants obviously are engineering works, even if we consider their inception to be due to the medical men.

8 Perhaps you ask why I should go into these details which are common knowledge, when their mention can give little additional information. My reason is that I want to emphasize the facts as a basis for the discussion of the question: What does the engineer owe to society when society owes so much to the engineer.

9 In the early history of the race when war was the almost constant condition, it was inevitable that the great warrior should become the leader and ruler of the people. As time went on, the engineer developed, as we know from the wonderful works of antiquity like the great aqueducts, the bridges, tunnels and roads; but, from the past, had come the tradition lodging leadership in the warrior caste, where it remained for many centuries, and indeed, has still a tendency to remain in monarchical countries.

10 During the last century, wars have been less frequent and

ue to the engineer, commerce has become so prominent that while
ie hereditary nobility still linger on the scene, their titles have be-
ome almost meaningless. This was particularly noticeable when one
f the English dukes served in the quartermaster's department dur-
ng the Boer war in a subordinate capacity, and still more so in the
ar between Russia and Japan, when only one Russian general was
member of the nobility.

11 I think you will see the point to which I am leading, namely,
hat in this "age of the engineer," he should not rest content simply
ith doing the work which makes for our comfort and happiness,
t the command of others, men who are lawyers or simply business
nen, but that the engineer himself should take a vital and directing
art in the administration of affairs. I know the objection that an
ngineer's professional work is so engrossing and exacting that he
annot become a politician in the sense that a politician is a man who
ives all his time to pulling wires and filling offices. This is doubtless
rue, but where it is a matter of self-interest, the engineer, like other
nen, can find time for this extra work.

12 We Americans are fond of claiming that we have the greatest
ountry and the most free and best government in the world.
That government, however, for i ts efficiencyand integrity depends
pon us as citizens, and it ought to be a matter of the greatest pride
o every American to do his part, so far as lies in him, to make the
ountry and its government better and happier every year.

13 In view of the enormously important part which the engineer
lays in the life of today, it is incumbent upon him, more than upon
nost other men, to take a vital interest in the work of government
nd to lend his trained ability and judgment to its perfection. I do
ot mean of course that the engineer should do routine professional
work for the government without compensation, but that in the dis-
ussion of public improvements and the administration of govern-
nental departments, he should take an active public stand to influence
nd guide the non-expert part of the population.

14 It is notorious that enormous amounts of money have been
squandered on great public works because they were undertaken in
a way which every engineer knew must be inefficient and uneco-
nomical. If all of us as engineers had a keen sense of our duty in this
espect, and would properly utilize our experience and ability through
he daily press, the magazines and the reviews, by public discussion,
nd in the daily intercourse of life, as well as by impressing the truth
pon our representatives in municipal and national affairs, I believe
we would accomplish an immense amount of good.

15 It will be understood, I am sure, that in this I refer almost entirely to the relations of engineers to society in general, and not to other professional men. For many years engineers have been most generous in making public to their technical brethren the results of their experience, and our own Proceedings are full of instances. It would be impossible to name more than a few, but perhaps the most notable case was that of Past-President Taylor in the publication of the results of his life work of research on the Art of Cutting Metals.

16 A problem of foremost importance at the present time is the management of labor to secure efficient work and satisfied men. It is probable that the direction of more than 90 per cent of the skilled labor is in the hands of engineers. Most emphatically is this a case where engineers owe a great duty to society. It is, therefore, an especial pleasure to recognize that some of our own members have played a foremost part in the best work that has been done in devising plans for compensating labor which will stimulate the men to their best efforts and reward them adequately. The names of Halsey, Taylor, Gantt and Emerson will at once occur to you.

17 It would be inappropriate in this brief address to attempt a detailed discussion of the labor problem, but I feel that I shall voice the sentiment of every one present when I say that the effort of every patriotic American should be exerted to maintain absolute freedom of contract in labor matters as in all others. Just as we are opposed to monopoly by capital, so we are to the same thing by labor.

18 No reasonable man objects to labor organizations, as such. They have undoubtedly been the cause of much benefit to the men. The danger with them, as with political organizations, is the formation of a machine which utilizes the organization solely for the selfish interests of the members of the machine. There can be no doubt whatever that many strikes are against the real wishes of a majority of the men, who are overborne by the machine and its adherents; and it is also true that the net result of nearly all strikes is an actual loss to the men. The problem is an exceedingly difficult one and requires the greatest wisdom, patience and tact for its complete solution; if, indeed, taking human nature as it is, we can ever hope for its removal from the list of worries of the manager of great enterprises.

19 Many questions prominently before the public are peculiarly such as require engineering knowledge for their proper understanding and regulation. The word trust has come to have such a sinister meaning that it is only necessary to fasten it upon an enterprise to render it criminal in the popular estimation. We have recently heard a great deal about the so-called Water Power Trust, the charge being

at all the available power sites were being grabbed so as to subject ır citizens at some future time to the payment of tribute for electric ›wer derived from them. I am not concerned, at the moment, with discussion of monopolies, which we all deprecate, but with pointing ıt that engineers know these water powers cannot be made avail- ble except by the expenditure of large sums of money. Indeed, it ·ould be easy to point out the fortunes that have been lost in the ttempted exploitation of these supposedly lucrative natural gifts. 'he general public is utterly misled by statements that these power ites are obtained for nothing, the idea being that the development s a matter of small expense. Here the engineer can do a work of eal benefit by disseminating correct information.

20 Again, in the consideration of public service corporations, the ngineer knows the cost of installation and operation, and so can dis- uss intelligently whether rates are fair or exorbitant, and whether apital represents real investment or water. These are problems f the greatest importance, and for their proper solution, the electo- ate needs training that can be given by no one else so well as by the ngineer.

21 About a year ago, at our Washington meeting, I did what I ·ould along this line by pointing out mistakes in connection with avy yard organization, and this illustrates very clearly what I am dvocating for all engineers. Here was a great department of the Government for which the annual appropriation now exceeds one undred millions of dollars. Its administration had fallen into the ands of a man who started to make changes in the entire adminis- ration which would have been ruinous to efficiency; and yet, hardly a oice was raised in opposition.

22 I do not mean to imply that engineers never show public spirit n such ways as I have suggested: there are too many instances to the ontrary. Our own Society and others which have taken part in the ovement for conservation of our natural resources have set a good xample, and other cases could be cited where individual engineers ave shown commendable enthusiasm. These, however, are mostly ases of unusual importance and relatively infrequent. What I am leading for is a habit of mind that will cause engineers to take an ctive part in all public questions, great or small, where their knowl- dge and experience will enable them to contribute to the common good.

23 The movement which has been set on foot by Congress to estab- lish a Bureau of Mines suggests an opportunity for the engineer to ake an active part in public affairs. I question whether this idea

might not be developed a little further by providing for a department with a Cabinet officer at the head, to be called the Department of Mines and Manufactures, with the scope implied by the title.[1]

24 When we think of the enormous values represented by the industries which would come within the purview of such a department, it seems only reasonable that they should be under the care of a Cabinet officer. If we are told that there is already the Bureau of Corporations, I would point out that the object of this proposed new department is quite different from that of the existing bureau which thus far, in the estimation of many, has done little or nothing to advance the interests of manufacturing, but has, in their opinion, disclosed a spirit which is almost inimical. The department that I have in mind would aim to stimulate improvement and progress in manufactures and industries generally, in somewhat the same way that the Department of Agriculture has done for the farmers.

25 We have often heard engineers complain that the profession does not receive due praise and credit for its splendid work. This is true enough, but is the reason not very largely because the engineer has hitherto been content to do the work and then fade into the background, leaving the talking and the management to the lawyer and the politician? With the advance of technical education, engineers are more and more becoming the high officials of our large corporations. It is to these men, whose talents and trained ability have made them the leaders in manufacturing and in business, that the country has the right to look for leaders in the affairs of government, and not until the engineer of all grades has done his part towards the promotion of the highest efficiency of the Government can he truly say that he is, in the fullest sense of the term, a good citizen of the Republic.

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[1]Since the time this address was prepared the bill in Congress referred to above has become a law. The newspapers have published an item that consideration was being given to the formation of a Department of Public Works. This is along the same general line as my suggestion above for a Cabinet officer to head a Department of Mines and Manufactures.

No. 1286

BALL-BEARING LINESHAFT HANGERS

By Henry Hess, Philadelphia, Pa.
Member of the Society

his paper is presented because of a request for more specific infor-
on made during the discussion of a paper that I was privileged to
at the Annual Meeting in New York, December 1909. That
r dealt with Lineshaft Efficiency, Mechanical and Economic, and
restricted to the presentation of actual measurements of the power
umption of the same lineshaft when mounted on plain and again
all bearings, with that change the only variable.

It was the purpose of the paper to describe merely the actual
and its results, thus adding to the fund of available engineering
wledge. The favorable economic showing of the ball bearing
herent in the advantages of rolling as compared with sliding fric-
, quite aside from any particular make of ball-bearing; though if
ability as well is to be secured, it naturally is essential that bear-
of correct design and suitable workmanship and material be
cted. The demand at the time of the discussion and since must
e as apology for such references to a product for which I am respon-
e as are incident to a description of the installation in question.

The first real improvement in hangers was made in this country
1848 by Edward Bancroft, the father of one of the oldest and
st honored members of our Society, who first mounted the box to
vel fully while well supported and who also gave it vertical adjust-
lity. The means are so familiar to every one today as to constitute
ommonplace. This original hanger was supplied with carefully
ed adjusting screws of liberal size; their ends terminated in
rectly machined spherical sockets fitting over correspondingly
chined spherical segments on the top and bottom of the box. Once
usted in the hanger the box retained its place until a readjust-
nt was demanded by some outside cause such as a settling building.

resented at the Spring Meeting, Atlantic City 1910, of The American
iety of Mechanical Engineers.

4 Unfortunately, the constant and incessant demand for lower and yet lower costs was given heed to by many until in course of time not a few of the many makes of hangers marketed are not machined at all, but are foundry jobs throughout. Even so, the consequent looseness and indefiniteness of position of the box supporting screws is not a very serious matter with plain bearings. The very length of the plain

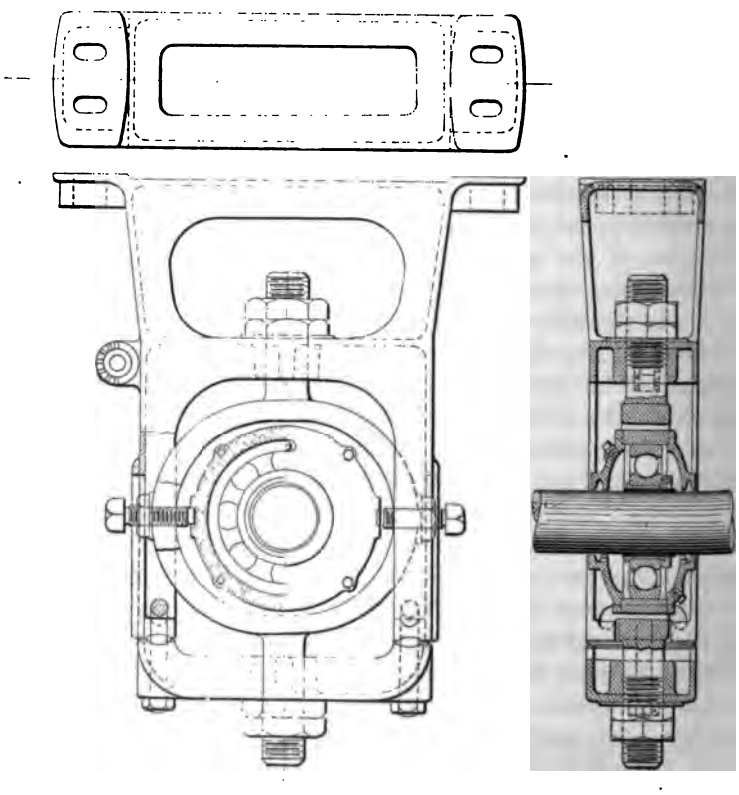

FIG. 1 ARRANGEMENT OF BALL-BEARING HANGER

bearing, equal to some four or five shaft diameters, helps to hold the box in line with the shaft if that is straight; or if the deflecting forces are too great, then the resultant excessive pressure on the plain bearings will draw attention to the trouble and by an insistent squeal, demand correction.

5 In first applying ball bearings to lineshafts I employed various

agers such as were on the market. The ball bearing was set in an closing box, which in turn was held between the same supporting ews that supported the plain bearing displaced. Occasional orts were received that the power consumption was greater after e change than before. These were particularly insistent from a few tallations where accurate meter records of electrical power consumed the shaft driving motors were kept. Investigation finally disclosed each instance a shifting of the shaft sections from their original gnment. The consequent and in several cases quite severe binding the shaft at each revolution consumed considerable power. Owing the very low coefficient, 0.0015, of ball-bearing friction, however, the ditional load on the ball bearings was without evident effect and used neither squealing nor even perceptible heating. Realigning e boxes immediately brought down the power consumption to the iginal low figure.

6 The Bancroft or, as they are better known, the "Sellers" type nger, with their definitely-machined supporting screws and sections spheres on the outside of the box to rock on, were not found practicle with ball bearings, because these spherical sections became too flat th the large diameter of the box containing the ball bearing, as is ident from an inspection of the cross section of such a box given in g. 1.

7 It was finally and reluctantly decided to make up and build ngers, general coöperation with the specialists in that line having en found impossible from lack of interest, reluctance to make anges, the usual inertia resisting innovations, etc.

8 Many designs were laid out on paper and some were tried, but carded as not responding to all of the following requirements of an al hanger:

a Definite support of the box on machined seats permitting no shifting under load.

b Ability of the box to swivel in all directions.

c Vertical adjustability of the box within the hanger body.

d Horizontal adjustability of the box within the hanger body.

e Rigidity in every direction, to permit the hanger to be used as a ceiling hanger, floor stand or post hanger.

f Convenience of adjustment in aligning the shaft.

g Adaptability for countershaft hangers involving a shifter-arm.

h Neatness of general outline and conformity to modern machine design by substituting box sections for ribbing.

i The lowest cost consistent with the other requirements.

9 The design finally evolved is shown in Fig. 1. The box is supported and pivoted horizontally on the ends of two screws tapped through the opposing sides of a yoke surrounding the box with enough freedom to give 1 in. of horizontal adjustment. This yoke has an upper and lower cylindrical stem, each turned to a running fit in the corresponding bore of the hanger; these stems are threaded and provided with nuts and checknuts and allow a vertical adjustment of 2 in. As the box can swivel horizontally in the yoke and that in turn vertically in the hanger the two together provide the desired universal swivelling freedom.

10 The hanger body is of channel section with the flat outside. The central crossbar takes the weight of the box and shaft and also materially stiffens the hanger. The lower crossbar is cast integrally with the hanger body and split off in the usual way. A single bolt at each end serves for attachment. This bolt is a drop forged T with the T turned down and ball ended to fit in corresponding sockets.

11 All of the various sizes, with the exception of the largest, which never comes into consideration for countershafts, are provided with cast-on lug with a serrated side face. To this may be bolted an arm of suitable length at any desired angle, to carry the usual eye guiding the shifter rod.

12 The construction of the bearing box is also apparent from Fig. 1, which shows it to consist of a central cast supporting ring bored to a sucking fit for the outer race of the ball bearing. To the side faces coverplates are bolted with an oil-tight joint and where these surround the shaft they are provided with a cored annular groove. The side lips are bored $\frac{1}{64}$ in. larger than the shaft diameter and have sharp edges.

13 This arrangement is found to be efficient in retaining the lubricant and so promotes cleanliness, while also preventing the entrance of ordinary foreign matter. For particularly difficult locations, as in cement mills, the very fine floating grit is kept out by a double groove, the outer one of which is filled with a fairly heavy grease. A single charge of heavy cylinder oil or non-acid grease will last the average lineshaft bearing several years; and to avoid total neglect refilling once a year is recommended.

14 The ball bearings are free endwise in the box. It is recommended that a lineshaft be held endwise by ordinary collars on either side of the central hanger so that all weaving endwise, due to expansion and contraction, settling, etc., is allowed for by the end freedom in the boxes. An occasional installation is found with heavy end-thrust, in which case the thrust is taken on one of the ball bearings by letting

ome up against the shoulders of the coverplates. Unusually heavy
ists are provided for by special hangers into which a collar type of
l bearing is built.

5 As it is necessary to clamp the ball bearing to the shaft so that inner race cannot rotate and as commercial shafting is somewhat eterminate in size, a so-called "adapter" is employed, the details which are shown in Fig. 2. The adapter consists of a bush fitting o the bore of the inner race, which in turn is fitted with a coned split eve. This latter is driven home endwise until the whole is tightly

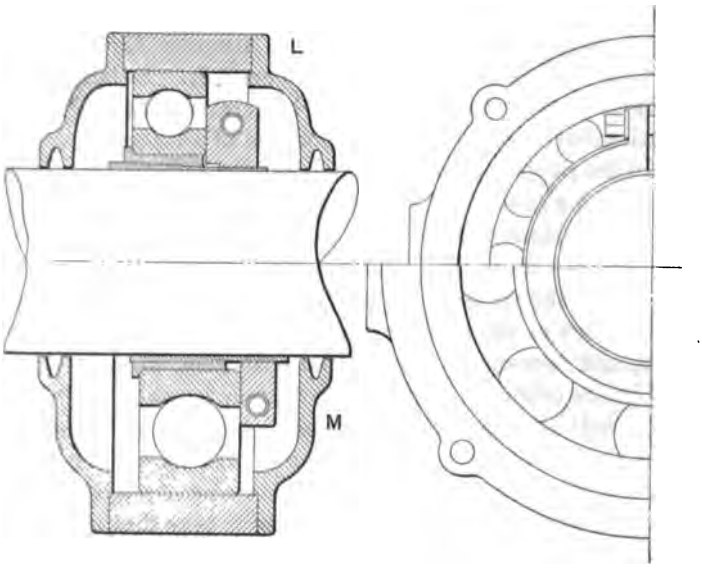

FIG. 2 BALL-BEARING ADAPTER

mped onto the shaft retaining a truly concentric setting. Unless ere is considerable vibration, the wedging effect of the small angl the conical bush is sufficient to prevent any loosening, but to guard gainst all contingencies a split collar is clamped onto the sleeve with face close up to the face of the bearing.

16 In the sectional view, Fig. 2, that part of the bearing above the nter line appears narrower than that below, the first marked "L" d the latter "M." This indicates the relative widths of light- eight and medium-weight bearings. Bearings of the "L" or light-

weight series take less load than those of the "M" or medium-weight series. For all ordinary lineshafts the light-weight series is quite sufficient; it is only for extraordinary conditions or for jackshafts, etc., that the medium series comes into consideration. A single medium bearing is sometimes also used in the hanger next to the main belt.

17 The ball bearing itself is a very simple element, consisting, as is clear from both illustrations, of an inner race, an outer race, and a single row of interposed balls running in grooves whose radius of curvature is only a few per cent larger than the ball radius. Races and balls are made of alloy steels (a special mixture of the carbon, chrome, manganese variety.)

18 These ball bearings are the same that are regularly supplied for the machine industries in general. Adapters for shafting range from $\frac{15}{16}$ in. to 3 $\frac{15}{16}$ in., both light and medium. As larger shafts are rarely of the nature of lineshafts, it is preferable to fit seats directly to the bearing bore without the interposition of adapters.

19 In the paper referred to at the outset direct measurements were cited showing a saving in lineshaft friction of about 35 per cent under proper belt tensions of 44 lb. to 57 lb. per inch width of single belt and correspondingly more for heavier loads. The return on the investment was also shown to be 37 per cent per annum, taking into account the higher cost of the ball-bearing installation. Such higher cost is, however, not necessary. The initial cost may, in fact, be actually lower if in the original layout full advantage is taken of the possibilities of the ball bearing. The ball bearing is as safe and reliable at 600 r.p.m. as at 200; whereas, the use of such high speed with plain bearings is beset with so many difficulties in the way of reduction of size of lineshaft, pulleys, drop of hangers, etc., as to take that practically out of consideration for the average plant. The first cost of a ball-bearing installation of 600 r.p.m. compares favorably with the first cost of one at 200 r.p.m. on plain bearings and the full advantage of the saving to be derived from ball bearings may thus be realized without any extra investment whatsoever.

20 In fact, the first cost of the ball-bearing equipment is quite likely to be less. As an example, it is fair to take a lineshaft such as that on which the test referred to in the former paper was made, but fully loaded to drive 32 machines. The installation elements that vary with the shaft speed are the shaft diameters, pulley diameters, hanger drops, belt widths and countershaft-driven pulleys.

The net cost of the installation material for the slow speed shaft of 200 r.p.m. on plain bearings transmitting 40 h.p. is	$558.95
The net cost of the alternate installation for the high-speed shaft of 600 r.p.m. on ball bearings is	441.87
The saving in first cost of material amounting to 21 per cent	$117.08

Appendix for details.

1 The lineshaft bearing friction saving, based on an average ficient of friction and confirmed by the series of tests cited in the vious paper, is 0.78 kw. or 2340 kw-hr. for a year of 3000 working rs and worth, at 3 cents per kw-hr., $70.20; secured by an instal- on 21 per cent lower in initial cost. See the Appendix for further ails.

APPENDIX NO. 1

COST OF PLAIN-BEARING SLOW-SPEED LINESHAFT MATERIAL

22 Shaft 200 r.p.m. in ring-oiling boxes, transmitting 40 h.p., driving 32 countershafts, one belt to each countershaft, 8 ft. to countershaft centers, countershafts 300 r.p.m.

10 hangers, 16-in. drop, ring-oiling babbitted boxes, net cost.....			$53.60
1 main pulley, 40-in. x 12½-in. double belt			
4 line pulleys	15-in. x 6¼-in. single belt	4 counterpulleys	10-in. x 6¼-in.
4 " "	8¾-in. x 4½-in. single belt	4 counterpulleys	6-in. x 4½-in.
4 " "	10-in. x 4¾-in. double belt	4 counterpulleys	6¾-in. x 4¾-in.
4 " "	9⅞-in. x 5½-in. single belt	4 counterpulleys	6¾-in. x 5¼-in.
4 " "	9¾-in. x 7¾-in. double belt	4 counterpulleys	6¾-in. x 7¼-in.
4 " "	8¾-in. x 4½-in. single belt	4 counterpulleys	6-in. x 4½-in.
4 " "	10-in. x 4¾-in. double belt	4 counterpulleys	7-in. x 4¾-in.
4 " "	12½-in. x 4½-in. single belt	4 counterpulleys	8-in. x 4½-in.
		Net cost.....	117.97
20-ft. 12-in. double belt			
320-ft. 3-in. single belt			
160-ft. 3-in. double belt			
80-ft. 3¾-in. single belt			
80-ft. 4-in. double belt			
		Net cost.....	360.10
72-ft. $2\frac{7}{16}$-in. lineshaft		Net cost.....	27.25
		Total net cost.....	$558.96

COST OF BALL BEARING HIGH-SPEED LINESHAFT MATERIAL

23 Shaft 600 r.p.m. in Hess-Bright medium series ball bearings, transmitting 40 h.p., driving 32 countershafts, one belt to each countershaft, 8 ft. to countershaft centers, countershafts 300 r.p.m. Lineshaft pulleys reduced in diameter by approximately one-half and the driven countershaft pulleys increased in diameter by approximately one-half; belts decreased in width in correspondence with the increased belt speed (ft. per min.); lineshaft decreased in diameter proportionately to increased speed (r.p.m.); under both conditions safe for 60 h.p. according to catalog ratings. Hanger decreased in drop to 10 in., rather more than the diameter of largest counterdriving pulley would require. Belts 50 lb. per inch width, single.

10-in. drop, medium weight ball bearings, net cost.....		$159.20
›y, 28-in. x 6½-in. double belt		
ys 7½-in. x 4½-in. double belt	4 counterpulleys 15-in. x 4½-in.	
ys 6-in. x 3½-in. single belt	4 counterpulleys 12-in. x 3½-in.	
ys 5-in. x 2½-in. single belt	4 counterpulleys 10-in. x 2½-in.	
ys 5-in. x 2¾-in. single belt	4 counterpulleys 10-in. x 2¾-in.	
ys 5-in. x 4½-in. double belt	4 counterpulleys 10-in. x 4½-in.	
ys 6-in. x 2 -in. single belt	4 counterpulleys 12-in. x 2 -in.	
ys 5-in. x 3 -in. single belt	4 counterpulleys 10-in. x 3 -in.	
ys 8-in. x 2 -in. single belt	4 counterpulleys 16-in. x 2 -in.	
	Net cost.....	87.57
ı. double belt		
ı. single belt		
ı. single belt		
ı. single belt		
ı. single belt		
—	Net cost.....	162.00
ı. lineshaft	Net cost.....	13.10
	Total net cost.....	$441.87

ESTIMATE OF SAVING IN KILOWATTS

› Author's paper on Lineshaft Efficiency, published in Transactions, r. 32, is given: Kw = 0.0000059 $Lds\mu$

		Plain Bearings	Ball Bearings
= total journal load in lb.	=	9606	5420
= shaft diameter in inches	=	$2\frac{7}{16}$-in.	$1\frac{11}{16}$-in.
= shaft speed in r.p.m.	=	200	600
= coefficient of friction	=	0.03	0.0015
= kilowatt friction loss	=	0.83	0.05

plain = $0.0000059 \times 9606 \times 2\frac{7}{16} \times 200 \times 0.03 = 0.83$

ball bearing = $0.0000059 \times 5420 \times 1\frac{11}{16} \times 600 \times 0.0015 = 0.05$

saving = $0.83 - 0.05 = 0.78$

DISCUSSION

FRANK B. GILBRETH. Is there any information available regarding a comparison of the manner in which concrete buildings and so-called mill buildings affect ball bearings? Nearly all engineers practicing in the construction of concrete buildings believe that the lack of vibration in this type of building lowers the cost of maintenance of lineshafting, hangers, bearings, and similar machinery.

CHARLES WHITING BAKER. One argument against concrete buildings is that the dust raised is injurious to the working parts of machinery. It would be interesting to know whether ball bearings will stand that dust better than plain bearings.

Where it is desired to dispense with lubricants, at least so that there shall be no dripping, does the ball-bearing lineshaft solve the difficulty?

FRANK B. GILBRETH. If the point about dust in concrete buildings is to be raised, they should be separated into two classes, those with wooden floors and those with concrete floors. There cannot be any dust in a concrete building with a wooden floor.

I would like to know what method is best in a concrete building for holding a lineshaft hanger to the ceiling; not only a ceiling with ribs, but also of the flat type. Hangers are usually of two types, those that can be located before the building is erected and those put in afterward. Concrete men have studied that subject a great deal but do not feel that they know the needs of the hanger men or of the bearing men.

F. W. DEAN. It is quite evident that wooden mill buildings must have the shafting lined up frequently to get minimum friction, but a concrete building is supposed to preserve its alignment after it is finished and set. There is great opportunity for the diminution of friction in mills. It is not always a question of bearings, but sometimes of the arrangement of driving machinery. In a mill where the friction load was 42 per cent of the running load, an examination showed that it was due to a great number of quarter-turn belts.

. N. VAN DERHOEF. In Par. 4 Mr. Hess referred to the early of hanger with ball-and-socket plunger screws and mentioned stress of modern conditions as leading up to modern hangers very little machine work. These conditions may have had e bearing, but experience has shown that extensive machine t is not necessary. Carefully fitted machine parts at the end of plunger screw are unnecessary because the vibration of the shafting level the bearing. After the box is in its proper position, it will there until the settlement of the building requires realigning of haft. With the ordinary hanger box, the pressure required at the to bring it into position is very slight. Accurate machine s, however, are proper and an absolute necessity in the case of bearings, where a single row of balls is used, because there is no rage, the balls being in direct line with the plungers. The fric- must be reduced to almost nothing or the bearing will tend to ap on the shaft.

n his list of desirable features for hangers, Mr. Hess mentions ontal adjustability of the box within the hanger body. This ther a mooted question on which are two widely different beliefs. is that the box itself should move across the hanger or frame and other is that the hanger body itself should be used as the movable y. Anyone who designs a four-point hanger will soon find diffi- ies in moving the box across the frame without introducing com- ations.

n regard to neatness of general outline and conformity to ern machine design by substituting box sections for ribbing, ness is desirable, but the substitution of box sections for ribbing nimportant. The amount of metal necessary in any cast-iron ger frame to take care of vibration enables almost any shape to sed which will have the requisite strength. It is rare for any cast- hanger to break under load.

ig. 1 shows the box itself carried by screws at the side, a con- ction similar to that in what is commonly known as the Boston ger, which has been used for a great many years in the eastern of this country. The defect of this type is that it carries the ht of the box directly upon the side screws and its swiveling in way is hard on such small bearings. To get horizontal adjust- t the box must be shifted out of the center line of the vertical ger screws, which is bad practice; or the vertical plunger screws t be shifted at the same time as the box. If the vertical plunger ws are left in a fixed position the center of the box is shifted out

of its correct location in line with the axis of the main screws. If the screws are shifted they must all be loosened and tightened up again every time the box is shifted sideways, Even then it is likely to be out of line vertically. Mr. Hess has approximated the solution of the problem by using a great deal of machine work and it is really necessary if these complicated adjustments are wanted. This type of hanger frame is needlessly expensive for ordinary conditions.

Mr. Hess mentions the advantage of running a shaft at high speed, say 600 r.p.m., and makes the statement that a shaft with ball bearings can be run at a higher speed than a shaft with plain bearings, but not long ago I saw a number of shafts 80 to 100 ft. long and about 2 11/16 in. in diameter, with plain bearings, running successfully at 700 r.p.m. The shafting and hangers were ordinary materials bought out of stock, without the seller knowing anything about the speed at which they were to run.

HARRINGTON EMERSON. For miscellaneous and scattered shops the power plant which is dependent on coal, cheapest to install and maintain, as well as cheapest and most reliable to operate, consists of:

a A gas-producer plant near a side track.
b Gas transmission by mains.
c Individual gas engines on main lineshafts running 400 to 600 r.p.m.
d Leather belt transmission to jackshafts and machines.

I therefore welcome ball bearings on lineshafts as an important aid to this form of power transmission. I much prefer the installation outlined to turbo-electrical generation, wire transmission and motor drives.

THE AUTHOR. If the dust from a concrete building is allowed to get into ball bearings they will be destroyed just as any other bearing would be under these conditions. The problem is to keep the dust out, and in the case of ball bearings it is an exceedingly simple matter to keep foreign matter out and the lubrication in under the most adverse conditions. This is done by extending the bearing box on each side enough to allow for two additional grooves in addition to the one usually employed. The two outer grooves prevent the dust from getting to the bearing and the third or inner groove traps the oil or other lubricant and drains it back to the bearing. Even in a marble plant, where the dust is considerable in amount and a more efficient cutting material than emery, no trouble has

en experienced with ball bearings and the lubricant is renewed ıt once each year. The same device has been successfully emoyed in submarine dredges under a 40-ft. head of water to keep e water out of the bearing and to prevent loss of the lubricant. The Thompson Meter Company in Brooklyn occupies a conete building and is equipped throughout with ball bearings with) trouble from the concrete dust. Even in mills where there is a ınsiderable quantity of lint floating in the atmosphere it never gets ıto the bearings.

Ball bearings were first applied to steam railroad passenger cars ı Europe and the first cars have now run over 600,000 miles. They ere originally charged with pale yellow vaseline and after they ad run 140,000 miles I found it still pale yellow in color. This ıdicates that there has been no deterioration in the lubricant and ıat the closure of the bearings was effective.

Regarding Mr. Jackson's question as to the advantages of ball earings at high speed, it is manifest that the plain bearing with eavy load is much more difficult to lubricate and must be more arefully looked after to insure sufficient lubrication than is necesary with the ball bearing. There is a general impression that the all bearing may be run without any lubrication whatever, but his is not true. If they could be made of absolutely incompressible ıaterial and absolutely true balls and races could be produced they ould probably need no lubrication. Furthermore, with high-speed ıeshafting using either plain or ball bearings, smaller pulleys can e employed, requiring a smaller drop in the hangers. The loads ın the bearings are therefore lighter and the belts are narrower and ess expensive.

The ball bearing which is loaded to three or four times its ated capacity will show a slight heating, hardly noticeable to the ouch. The amount of excess pressure put upon such a bearing by ı large shaft that has gotten out of alignment is too small to show tself by heating. In fact, one of the troubles with users of ball earings, particularly where thrust bearings are used, is the failure o realize that the friction is so little that even when the bearing is greatly overloaded that fact does not manifest itself in greatly ncreased resistance, as is the case with plain bearings. A bearing which is so overloaded that it shows additional resistance to turning or an appreciable rise in temperature is so seriously overloaded that it will soon be destroyed.

The question as to the relative frequency of alignment in mill

buildings and the more rigid concrete buildings carries its own answer; the more rigid a building the less frequently will it be necessary to realign. When the building moves, the bearings have to be realigned. The difference between plain and ball bearings is that the former, in case of a considerable shift, will squeal and require attention, while the latter remains quiet, does not heat and its life is not even affected, because it has a sufficient margin to take care of such overloads. Nevertheless, such shifting should not be neglected because the work done in bending the lineshaft has to be paid for as power consumed. The proper thing to do is to put bearings in a hanger in which they cannot shift and thereby realize the benefits of rigid hangers and bearings.

The mill mentioned by Mr. Dean as having a 40 per cent friction load was probably a textile mill. In such mills the power is so large an element of the total cost that it is usually looked after very carefully. The shafting is generally well aligned, the hangers, bearings, etc., all receive close attention and frequent oiling, and consequently the best results as to low friction losses. In most industries a totally different state of affairs prevails. In machine shops, for instance, the friction load of lineshafting and countershafting almost always exceeds 50 per cent, and in many cases it is as high as 65 and 70 per cent. In the Utica plant referred to, the substitution of ball bearings for plain bearings would have reduced the friction losses 60 to 90 per cent.

It has been stated that lineshafts with plain bearings were running satisfactorily at 700 r.p.m. There is no reason why such shafts cannot be run at 1700 r.p.m. except for the necessity of far greater care in maintenance and the relative friction loss. The ball-bearing lineshaft can be run at 600 r.p.m. without attention from one year's end to another; it is not even necessary to realign it, except for the power loss in bending the shaft. The limit of speed is not set for the ball-bearing lineshaft by the bearing, but by the requirements of the machine to be driven. In many cases they run at 17,000 r.p.m., but 600 r.p.m. is about the highest practicable for the average machine shop countershafts, where the pulleys must not be too small to secure sufficient belt contact.

The point was raised against the type of hanger described in the paper that when the box is shifted from the center of the hanger in the realigning, the shaft is out of line with a vertical drawn through its two supports. If the belts from the lineshaft were running vertically downward, the argument would be a valid one, and in

a case it would be desirable to have the bearing centered in its port and coincident with the line of belt pull. Ninety-nine per of the belts, however, are run much more nearly horizontal in any other direction. Those that do not run absolutely zontal runs at some angle, usually but slightly deviating. This the pull in line with the horizontal support of the box and normal he vertical supports. Therefore a cross-aligning movement of box is of no moment. The principal requirement is that the ger be sufficiently stiff. In the one described in the paper the is of cast iron and the two vertical members cast with it have a iderable diameter and therefore sufficient stiffness.

No. 1287

PERIMENTAL ANALYSIS OF A FRICTION CLUTCH-COUPLING

By Prof. Wm. T. Magruder, Columbus, O.

Member of the Society

he following series of experiments was recently made to determine results from the application of a known force at the end of the ter lever of a friction clutch-coupling. Several 24-in., four-jaw tion clutch-couplings were used. They were the stock couplings le by the Falls Rivet & Machine Company, of Cuyahoga Falls, O. ey consisted of the usual shifter lever, fork, yoke and cone, sliding the driving shaft. The clutch arm *G*, Fig. 1, was a heavy casting ed to the shaft. Guide surfaces *H* were machined in each arm the casting *G*, in which slid the inner jaws *I* and the outer jaws *J*. ch of the four pairs of jaws *I* and *J* was connected by pins *K* to the dge-block *L*, which was fulcrumed at its center *M* in the clutch- n casting. The wedge-blocks *L* carried adjustable steel wedges whose inner ends *O* engaged the short and hardened ends *P* of the nd levers *Q*, and whose longer ends *R* were operated through the uble links *F* by the sliding cone *E*. The inner and outer jaws gaged the annular ring *S* which was keyed to the driven shaft. his ring was 24 in. external diameter and 23 in. internal diameter. he eight jaws were each lined with a maple block 2½ in. by 9 in. size.

2 The tests included five lines of investigation:

First: To determine the forces required to throw in the shifter lever at different speeds when the clutch was in motion and when the clutch was at rest, and before and after the load had caused the clutch to slip on the ring.

Second: With different adjustments of the wedges, to determine the relation of the forces applied at the end of the

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shifter lever at different points in its motion and the corresponding axial forces, to the forces caused thereby to be exerted by the clutch shoes upon the ring of the clutch pulley.

Third: To determine the frictional resistances between the clutch shoes and the ring of the clutch-coupling, in motion and at rest under different loads.

Fourth: To determine the power transmitted for different adjustments of the wedges corresponding to different forces required to throw in the shifter lever, including the

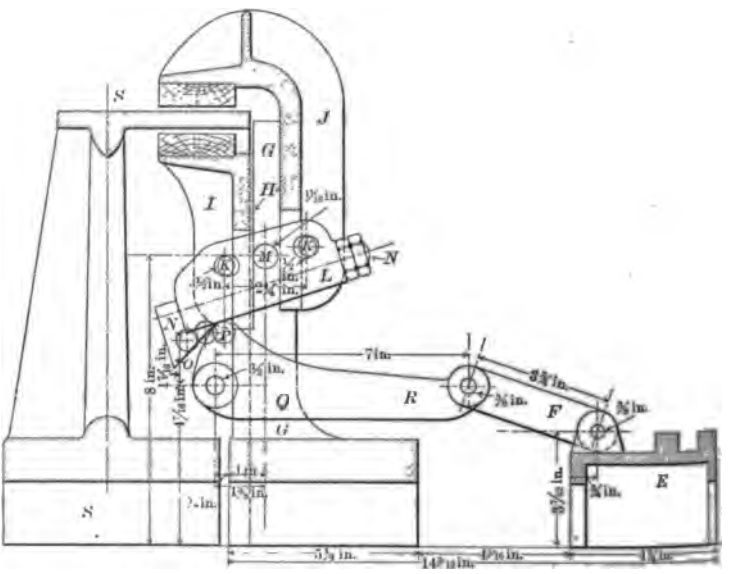


FIG. 1 HALF SECTION OF FRICTION CLUTCH-COUPLING.

maximum power which the clutch was capable of transmitting, and the maximum power which it was capable of picking up from rest.

Fifth: To determine the relation of the maximum forces applied at the end of the shifter lever, and the corresponding axial forces, to the maximum power transmitted by two-arm and four-arm clutches for the same adjustment of the wedges.

3 To make these tests, two machines were designed and constructed, as follows.

DYNAMIC CLUTCH-TESTING MACHINE

4 To determine the maximum power which a clutch was capable ' transmitting when the load was either gradually applied or picked ɔ from rest, the dynamic clutch-testing machine, Fig. 2, was used. ; consisted of floor-stands U, two co-axial shafts D and T, $3\frac{7}{16}$ in. ı diameter, and a large belt pulley V on the end of the driving shaft ', to which power was delivered. The clutch-coupling G was placed ear the middle at the junction of the two shafts. The coupling was eyed to the driving shaft D, and the clutch-ring S was keyed to the riven shaft T. On the opposite end of the driven shaft the brake ulley W was keyed. The shifter-lever A was operated in a hori- ontal plane. The motions required to throw in the clutch-cone E ere measured. The lever A was operated by hand power, or by crew power B, from behind a screen Y made of planks and used for he protection of the persons engaged in the test. There was a hori- ontal slit in it for the motion of the lever.

5 To measure the force exerted on the end of the shifter lever, a alibrated spring-balance X was used. It was of 300-lb. capacity, ınd was graduated by 5-lb. divisions.

6 The power was absorbed by a prony brake Z from the internally- langed, flat-faced pulley W, 48 in. in diameter, and 24 in. face. The length of the brake arm Z was $72\frac{5}{32}$ in. The brake constant was 0.001,145 b.h.p. per lb. per revolution. The effort exerted by the brake beam was measured by a platform scale C of 2000 lb. capacity. The leverage of the shifter lever A, when normal to the shaft D, was 4.939 in the dynamic clutch-testing machine. It is to be regretted that the power available was not sufficient to keep the speed uniform at 100 r.p.m., and for this reason the machinery slowed down to 92 r.p.m. under the heaviest loads.

STATIC CLUTCH-TESTING APPARATUS

7 In order to determine the force with which the shoes pressed against the clutch ring when a given maximum force was required to throw the shifter lever into operation, a static clutch-testing apparatus, Fig. 3, was used. It consisted of a clutch arm G mounted on a vertical shaft D supported in a flange coupling fixed to a struc- tural steel frame a. Only the two opposite arms of the clutch were used in this apparatus. The inner jaws were removed. The shoes of the two outer jaws J were caused to press upon a dummy

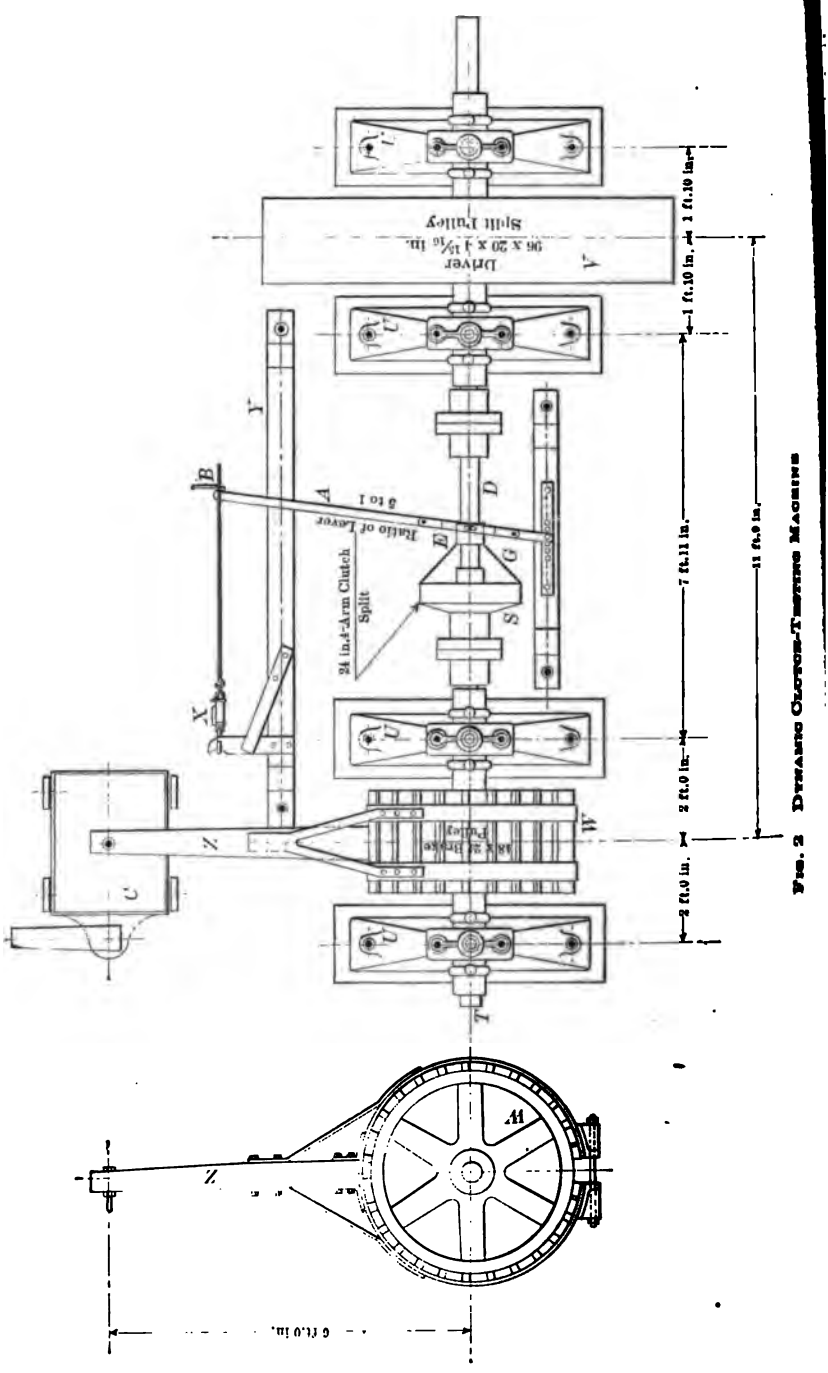


FIG. 2 DYNAMIC CLUTCH-TESTING MACHINE

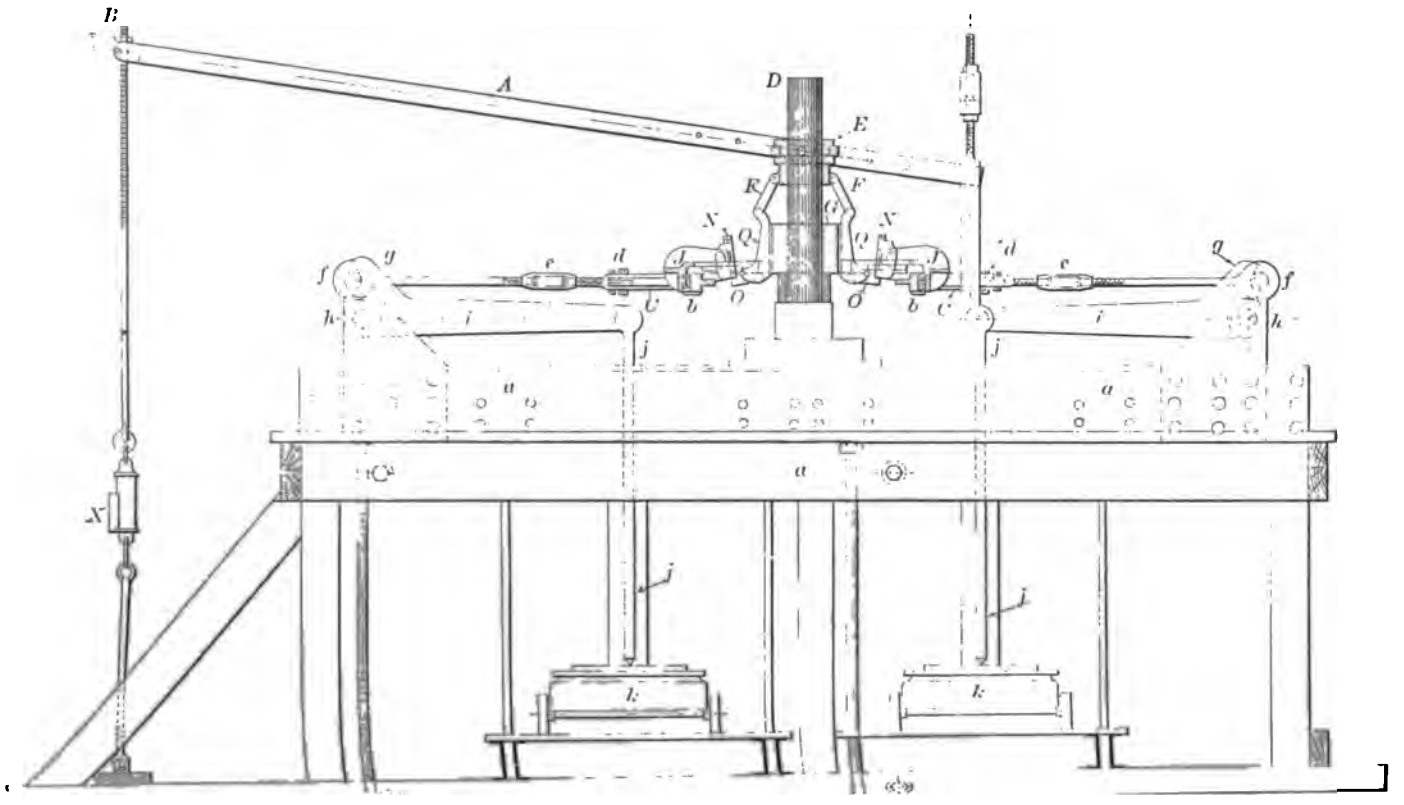
ıade up of two separate cast-iron segments *b*. Each of these nts was connected by the links *C* to the yoke *d*, which in turn ɔnnected through turnbuckle *e* to an eye carrying double knife *f*, which engaged the short and vertical end *g* of a bell-crank ulcrumed on a knife edge *h* in the frame *a* of the apparatus. To ıger and horizontal arm *i* of the bell-crank lever was knuckled ical prop *j*, the lower end of which was conical and which bore enter-punch mark made in an iron bar resting upon a platform :, of 600 lb. capacity. The ratio of the arms was seven. Two rm scales were used, one for each dummy ring segment.

The parts of the mechanism were adjusted so that the knife were kept in position and bore fairly. The ring segments were ıted that their external diameter was 24 in., or the same as the ring. This was done by means of the turnbuckles. When ıg segments were in this position the wedges were adjusted to the maple shoes bear evenly. The shifter lever was thrown in ew power *B* and the force so required was measured frequently inite intervals which were determined by measuring the dis- which the cone *E* had been moved from its original position. verage of the shifter lever *A*, when normal to the shaft, was to 1 in this apparatus.

In using the dynamic clutch-testing machine, the maple shoes irst adjusted by means of the wedge nuts so that they bore '. They were then burned in by driving the shaft *D* and the ng *G* while the ring *S* was prevented from rotating. The nuts were then adjusted again to make the shoes of both and inner jaws bear evenly on the ring when the shifter lever ırown in.

This adjustment was tested by means of 16 copper strips, ½ le, 0.002 in. in thickness, one used at each end of each shoe. shoes did not bear evenly, or at least as well as they are sup- usually to do in ordinary good millwright's practice, the wedge were screwed up, the ring blocked from rotating, the lever n in, and the shoes again burned in. By this means fairly uni- results and even pressures were obtained between the eight and the ring. With the shifter lever thrown in and the copper just capable of being pulled out by hand, the counting of the ɔns of the wedge nuts was begun. Similar adjustments were on the static clutch-testing apparatus, except that the shoes had surfaced but not burned in.

In the tests, the wedge nuts were all screwed up, one turn or


B
A
D
E
F
F
G
N
N
Q
Q
J
J
d
d
e
e
g
g
f
f
h
h
i
i
C
C
b
b
O
O
j
j
a
a
a
X
j
j
k
k

, a time, and the tests made, then another turn, and so on. the shifter lever A was thrown in by hand power, a man applied ıscular effort to the spring balance X on the end of the lever; it was thrown in by screw power, the tail-nut B was rotated. ›ring balance had a maximum indicator besides the usual one. ıotions of the cone E of the different couplings tested varied 4 in. to 4½ in. Readings of the spring balance were usually for each ¼-in. or ½-in. motion of the cone.

FIRST SERIES OF TESTS

These were made to determine the forces required to throw in ifter lever at different speeds, when the clutch was in motion hen the clutch was at rest, and before and after the load had l the clutch to slip on the ring.

Tests G, H, I, and M were made on the dynamic clutch-test- achine. The forces required to throw in the shifter lever by power and by hand power when the shafts were at rest were :termined, the machine then started up, and the brake tightened :he clutch-coupling slipped on its ring. The brake was then ed and another test made with the result that less power was ıitted. The wedge nuts were then tightened and the forces ed to throw in the shifter lever were measured one or more and the test contained, as given in Tables 1 and 1*a*. In Tests 'able 1*a*, readings of the forces required to throw in the · lever were taken both when the shafts were at rest and when ·ere in motion. The shifter lever was thrown in several times he power determined for a fixed setting of the brake nuts. were then tightened, and another set of four or more readings of the force required to throw in the shifter lever by hand when the shaft was in motion.

With the wedge nuts screwed up two and one-half turns it ·d a maximum of 70 lb. to throw in the shifter lever by screw . Immediately thereafter it required maxima of 55 lb. on the ·ial, 45 lb. on the second trial, and 43 lb. on the third trial, to in the shifter lever by a steady pull by hand power. This that the force required to throw in the shifter lever by hand was much less than by screw power. While this was partly · the friction of rest being greater than the friction of motion, also partly due to the various parts of the clutch adjusting elves to the conditions after one or two engagements of the

shoes with the ring. This has been frequently noted in practice in the shop.

15 With the same adjustment of the wedges, the clutch slipped when transmitting 84.6, 71.1, and 65.0 h.p., on the first, second, and third sets of trials. This reduction in the brake load shows the effect of wear of the clutch shoes due to the slipping on the ring. This was also indicated by the fact that it required a maximum of only 31 lb. to throw in the shifter lever by hand power after the test.

TABLE 1 FORCES REQUIRED TO THROW IN SHIFTER LEVER AND HORSE-POWER TRANSMITTED

Dynamic Clutch-Testing Machine

Wedges Set Up Turns	Distance From Start	Max. Force Required to Throw in Lever with Shaft at Rest By			Corresponding Axial Pressure, Shaft at Rest By		Gradually Applied Loads		
		Screw Power	Hand Power	Ratio	Screw Power	Hand Power	Net Brake Load	Rev. per Min.	Brake Horse-Power
Tests G 24-in., Four-Arm, Solid Clutch-Coupling									
1.5	2.75	56			277		581	96	63.9
							497	96	54.6
							471	96	51.8
2.5			119			588			
			94			464			
			75			371			
3.0			92			454			
			75			371			
3.5			114			563			
			92			454			
			92			454			
3.5	2.5	103	91	0.883	509	450	1185	92	124.8
		87*			430*				
Tests H 24-in., Two-Arm, Solid Clutch-Coupling									
3.5	2.5	45			222		471	96	51.8
							491	96	54.0
							486	95	52.9
4.0	1.875	114			563				
	2.25	111			548		735	95	79.9
		80*			395*				

* After test and after slipping.

TABLE 1—Continued

ance om art	Max. Force Required to Throw in Lever with Shaft at Rest By			Corresponding Axial Pressure, Shaft at Rest By		Gradually Applied Loads		
	Screw Power	Hand Power	Ratio	Screw Power	Hand Power	Net Brake Load	Rev. per Min.	Brake Horse Power
	Tests I 24-in., Four-Arm, Split Clutch-Coupling							
.5	70	55	0.79	346	272	.....	.....	.....
.....	.....	45	0.64	.....	222	.....	.....	.....
.....	.....	43	0.61	.....	212	739	100	84.6
.....	.....	.....	.....	.....	.....	621	100	71.1
.....	.....	.....	.....	.....	.....	568	100	65.0
.....	.....	31†	0.44†	.....	153†	.....	.....	.....
.....	85	65	0.76	420	321	.....	.....	.....
.....	.....	67	0.788	.....	331	915	96	100.6
.....	.....	55	0.646	.....	272	.....	.....	.....
.....	.....	53	0.623	.....	362	.....	.....	.....
.25	133	99	0.74	657	489	.....	.....	.....
.....	.....	100	0.75	.....	494	1216	94	130.9
.00	179	139	0.78	884	689	.....	.....	.....
.....	.....	119	0.67	.....	588	.....	.....	.....
.....	.....	119	0.67	.....	588	.....	.....	.....
.....	.....	117	0.65	.....	578	1371	93	146.0
	Equivalent horsepower at 100 r.p.m.						100	157.0

and after slipping. Reduction in b.h.p. shows effect of wear of shoes.

er two more sets of trials with tighter adjustments of the 30.9 h.p. was transmitted at 94 r.p.m.

th the wedge nuts screwed up four and one-half turns, it , maximum of 179 lb. to throw in the shifter lever by screw d of 119 lb. to throw it in by a steady pull by hand, corre- to 884 lb. and 588 lb. respectively, of axial thrust. Under litions, when transmitting 146 h.p. at 93 r.p.m., the split oke. This corresponds to 157 b.h.p. for a speed of 100 id is 78.5 per cent of the breaking load carried by the solid clutch.

)m Tests G and I, Table 1, it will be seen that the force o throw the shifter lever in by a steady pull by hand power, me, varied from a minimum of 66.5 per cent to a maximum r cent, averaging about 76.8 per cent of the force required in the shifter lever by screw power; and that the force

TABLE 1a FORCES REQUIRED TO THROW IN SHIFTER LEVER AND PICKUP LOAD

Wedges Set Up Turns	Max. Force Required to Throw in Shifter Lever. Shaft at Rest: Screw Power	Shaft at Rest: Hand Power	Shaft in Motion: Hand Power	Ratio	Number of Trials Averaged	Corresponding Axial Pressure. Shaft at Rest: Screw Power	Shaft at Rest: Hand Power	Shaft in Motion: Hand Power	Pick-up Load: Actual Net Brake Load	Pick-up Load: Estimated r.p.m.	Pick-up Load: Equivalent Brake Horse-Power
Tests M 24-in. Four-Arm, Solid Clutch-Coupling											
2.0	67				1	331					
		61		0.91	3		301				
			58	0.87	5			258	94	102	11.0
			44	0.67	4			217	206	100	22.6
3.0	124				4	612					
			93		5			459			
			86		4			425			
			69		4			341	543	96	59.7
4.0	140				1	692					
	125				6	617					
		115			4			568			
		105			5			519	501	96	55.1

required to throw in the shifter lever by hand power, after the test, varied from 44.3 per cent to 64.6 per cent, averaging 54.5 per cent of the force required to throw in the shifter lever by screw power before the test. From Tests I, the ratio of the forces required to throw in the shifter lever by hand power, before and after the tests, varied from 31/45 = 68.8 per cent to 54/66 = 81.8 per cent. It is to be noted that when the four-arm solid clutch broke, when transmitting 187.8 h.p., its wedges had been adjusted so that it required a maximum of 114 lb. to throw in the shifter lever by screw power, corresponding to a maximum of 563 lb. axial thrust. With the same axial thrust applied, the 24-in. two-arm clutch slipped when transmitting 79.9 h.p., or only 42.5 per cent thereof.

19 Tests L, Table 2, were made on the static clutch-testing apparatus. They give the forces required to throw in the shifter lever by screw power and by hand power. The ratios are higher than those given in Table 1 because there was no intermediate starting up, slipping and wearing of the clutch shoes. The last two tests were made with only one jaw in service, the other being disconnected.

20 From these tests it will be seen that the force required to throw in the shifter lever slowly and steadily by hand power averages on the static apparatus 88 per cent and on the dynamic machine about 79 per cent of that required to throw it in by screw power;

this ratio is reduced to about 0.68 by repeated trials of the hanism when at rest; that the ratio of the forces required to w in the shifter lever when the shafts are in motion and are at varies from 0.91 to 0.87 according to the number of slippings of clutch on its ring, and may be reduced even to 0.67 after several ings.

.E 2 TESTS L FORCES REQUIRED TO THROW IN SHIFTER LEVER, AND PRESSURES EXERTED BY CLUTCH-SHOES ON CLUTCH-RING

ON STATIC CLUTCH-TESTING APPARATUS. 24-IN., FOUR-ARM, SOLID CLUTCH-COUPLING, USING ONLY TWO OUTER JAWS

Distance from Start	Max. Force Required to Throw in Shifter Lever Shaft at Rest by			Corresponding Axial Pressure Shaft at Rest by		Net Platform Scale Readings Corresponding to				Actual Shoe Pressures Corresponding to Maximum Force. Lever Ratio = 7					Ratio Column 16 to Column 3
						Column 3 Max. Net				To Throw in Lever		On Shoes		Total on Shoes	
	Screw Power	Hand Power	Ratio	Screw Power	Hand Power	W	E	W	E	W	E	W	E		
2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	44	....	.....	214	....	150	160	263	271	1050	1120	1841	1897	3738	85
1	44	....	.....	214	....	173	182	.....	.....	1211	1274	.....	.....	.....	.....
1	59	51	0.86	287	246	179	192	330	339	1253	1344	2310	2373	4683	79
	77	68	0.86	374	331	207	225	400	409	1449	1575	2800	2863	5663	74
	85	77	0.91	413	374	226	234	417	419	1582	1638	2919	2933	5852	69
	97	90	0.92	472	435	203	216	453	460	1421	1512	3171	3220	6391	66
	134	109	0.81	652	530	227	252	535	544	1589	1764	3745	3808	7553	56
	110	100	0.91	535	486	249	261	500	504	1743	1827	3500	3528	7028	64
	157	134	0.86	763	652	289	310	594	600	2023	2170	4158	4200	8358	53
Average			0.88	....	....	....	....	....	....	....	....	....	....	....	68
	33	29	0.88	160	141	125 out of		277	....	875	.....	1939	.....	.....	.....
	52	48	0.92	253	233	180 service		394	....	1260	....	2758	.....	.....	.....

imum force required to throw in shifter lever acting on outer jaw of only one arm:

By screw-power	33 lb.
By hand-power, steady pull	29 lb.
By hand-power, rapidly	31 lb.
By hand-power, more rapidly	37 lb.
By hand-power, suddenly, or by jerk	55 lb.

SECOND SERIES OF TESTS

The series was made to determine with different adjustments ıe wedges the relation of the forces applied at the end of the er lever at different points in its motion and the corresponding l forces, to the forces caused thereby to be exerted by the clutch s upon the ring of the clutch-pulley.

TABLE 3 TESTS L FORCES REQUIRED TO THROW IN SHIFTER LEVER AN CORRESPONDING PRESSURES EXERTED ON PLATFORM SCALES

TESTS ON STATIC CLUTCH-TESTING APPARATUS. 24-IN., FOUR-ARM, SOLID CLUTCH-CORE USING ONLY TWO OUTER JAWS

Distance Cone is Moved	Corrected Spring-Balance Readings of Forces Exerted at End of Shifter-Lever	Corresponding Net Platform Scale Readings	
Inches		West	East
¼	18	8	12
½	43	55	65
¾	53	102	116
1	57	144	150*
1¼	59	179	192
1½	58	209	222
1¾	53	235	248
2	51	256	269
2¼	48	271	287
2½	43	290	304
2¾	38	303	314
3	33	312	323
3¼	32	318	330
3½	26	321	335
3¾	23	326	337
4	16	328	339
4¼	8	330	339
4½	0	329	339†

* Maximum Force required to throw in shifter-lever.
† Maximum pressure on shoes.

22 Table 2 gives the results of the tests with the static apparat The maximum forces required to throw in the shifter lever by sc power and by hand power, and their ratio, the correspond axial pressures, the corresponding net platform-scale readings, the actual shoe-pressure readings for these two maxima, are giv "W" and "E" mean "west" and "east" and refer to the relat positions of the two scales on the left and right-hand sides res tively, as in Fig. 3.

23 Comparing the figures in the last column, which give the r of the sum of the maximum actual shoe pressures to the maxim force required to throw in the shifter lever, it is seen that the f ratio varies from 85 for three turns of the wedge nuts to 53 for e turns of these nuts, with an average of 68. This shows that efficiency is much greater under the lesser pressures.

24 The two tests at seven turns show the effect of compres in the form of set, not only on the shoes but on the various parts joints of the clutch.

LE 4 TESTS F FORCES REQUIRED TO THROW IN SHIFTER LEVER, AND HORSEPOWER TRANSMITTED

S ON DYNAMIC CLUTCH-TESTING MACHINE. 24-IN., FOUR-ARM, SOLID CLUTCH-COUPLING

ges Set Up, Turns	Distance From Start	Max. Force Required to Throw in Shifter Lever, Shaft at Rest	Corresponding Axial Pressure, Shaft at Rest	Gradually Applied Loads.		
		By Screw-Power	By Screw-Power	Net Brake Load	Rev. per Min.	Brake Horse-Power
	2¼"	51	252	556	90	57.3
	.....	.....	.....	666	94	71.7
	.....	.....	.....	606	97	67.3
more turn.....	2⅜"	97	479	1112	92	117.1
more turn.....	2½"	114	563	1665	94	179.2
				1745	94	187.8
	Equivalent horsepower at 100 r.p.m.....				100	199.8

5 The following statements are deduced from the results of this es of tests:

a The average ratio of the maximum forces required to throw in the shifter lever with one and two jaws was 0.55.

b The average ratio of the corresponding forces exerted on the ring with one and two outer jaws, counting the forces exerted by only one jaw in each case, was 0.79.

c The average ratio of the corresponding forces exerted on the ring with one and two outer jaws, counting the forces exerted by both the jaws, was 0.38.

d The average ratio of the maximum forces exerted on the ring with one and two outer jaws, counting the forces exerted by only one jaw in each case, was 0.85.

e The average ratio of the maximum forces exerted on the ring with one and two outer jaws, counting the forces exerted by both the jaws, was 0.42.

f In other words, 55 per cent of the force applied at the shifter lever produced only 38 per cent as much corresponding force exerted on the ring, and only 42 per cent as much of the maximum force exerted on the ring, for one jaw rather than two jaws. This was doubtless due to the inequality of the pressures exerted when only one arm was in use, and shows the desirability of so adjusting the wedges of the opposite arms that the shoes bear equally.

26 Table 3 shows the relation of the motion of the cone to the maximum force required to be applied at the end of the shifter lever and to the forces exerted by the clutch shoes upon the dummy ring-segments in Tests L, and is a fair sample showing that the maximum force exerted on the shifter lever does not produce the maximum force exerted on the clutch shoes.

TABLE 5 TESTS N FORCES REQUIRED TO THROW IN SHIFTER LEVER, AND HORSEPOWER TRANSMITTED WITH GRADUALLY APPLIED AND PICK-UP LOADS

TESTS ON DYNAMIC CLUTCH-TESTING MACHINE 24-IN., FOUR-ARM, SOLID CLUTCH-COUPLING

Wedges Set Up, Turns	Distance From Start	Maximum Force Required to Throw in Lever, Shaft at Rest By Screw-Power	Corresponding Axial Pressure, Shaft at Rest By Screw-Power	Gradually Applied: Net Brake Load	Gradually Applied: Rev. per Min.	Gradually Applied: Brake Horse-Power	Suddenly Applied Loads: Net Brake Load	Suddenly Applied Loads: Rev. per Min.	Suddenly Applied Loads: Brake Horse-Power
3	2.5	53	263	711	96	78.2	471	96	51.8
3	2.75	43	212*						
4	2.25	90	445	1035	92	109.0	471	96	52.0
4	2.5	58	286*						
5	2.25	125	617	606	96	66.6	491	96	55.1
				606	96	66.6	561	96	61.7
				746	94	80.5	628	95	68.3
				621	93	66.1	981	91	102.2
							986	91	102.7
		Equivalent horsepower at 100 r.p.m.						100	112.9

* After slipping three times.

THIRD SERIES OF TESTS

27 The third series of tests was made to determine the frictional resistance between the clutch shoes and the ring of the clutch-coupling in motion and at rest.

28 For these tests, a cast-iron plate, $1\frac{15}{16}$ in. thick, 12 in. wide, and 36 in. long, and maple blocks $2\frac{7}{32}$ in. thick, 3 in. wide, and 9 in. long were used. The angles of inclination of the plate at which a block would begin to slide from rest, and at which it would continue to slide after being started into motion, were taken as the angles of friction respectively for the two cases. The horizontal forces required to be exerted in order to start the block from rest, and to continue it in motion when placed on the carefully leveled plate, were taken to be the natural tangents of the angles of friction respectively for the weights carried by the block.

) The smoothness of finish of the block, the uniformity and ness of the bearing surface, the deflection of the plate, the cush- of air between the block and the plate, each has its effect on angle of friction.

0 The number of tests made with flat maple blocks does not rrant the drawing of very positive conclusions, but it would seem t the average frictional resistance under load was greater from rest n the resistance under load in motion, in the proportion of the gent of 18.5 deg. to the tangent of 13.3 deg., or in the proportion 0.33 to 0.24.

FOURTH SERIES OF TESTS

1 The next series of tests was to determine the power trans- ted for different adjustments of the wedges corresponding to erent forces required to throw in the shifter lever, including the ximum power which the clutch-coupling was capable of trans- ting, and the maximum power which it was capable of picking from rest.

2 For these tests, the dynamic clutch-testing machine was used. wedges were adjusted so that the shoes bore fairly equally. determine the maximum power which the clutch-coupling was able of transmitting, the wedge nuts were gradually tightened, the brake screwed up either until the coupling slipped, in which the wedge nuts were tightened up further, or else the clutch ke. Table 4 gives the results of this set of tests, from which it be seen that with a maximum of 114 lb. applied by screw power he end of the shifter lever, corresponding to an axial thrust of 563 when revolving at 94 r.p.m. under a net brake load of 1745 lb., clutch transmitted 187.8 h.p., under which condition the clutch ped, the speed varying from 94 to 98 r.p.m., and both clutch and broke. This corresponds to 199.8 b.h.p., or practically to a ximum of 200 b.h.p., for a speed of 100 r.p.m.

3 Table 5 gives the results of the tests with the dynamic clutch- ing machine, of the forces required to throw in the shifter lever, the horsepowers transmitted with gradually applied and suddenly lied loads. The latter are what are sometimes called pick-up ls. From this table it will be seen that with a net brake load of lb., when running at 91 r.p.m., the clutch picked up 102.7 h.p. had it started when the clutch broke. It had just previously ed up 102.2 h.p. This corresponds to 112.8 maximum b.h.p. ick-up load for a speed of 100 r.p.m.

FIFTH SERIES OF TESTS

34 The last series was to determine the relation of the maximum forces applied at the end of the shifter lever and the corresponding axial forces, to the maximum power transmitted by two-arm and four-arm clutches for the same adjustment of the wedges.

35 To perform this test on the clutch which had been tested in the dynamic clutch-testing machine (See Tests H of Table 1), the two opposite pairs of jaws were disengaged by unscrewing their wedge nuts, and retaining the same adjustment on the two other pairs of shoes. It was found that it then required a maximum of 45 lb. to throw the shifter lever in by screw power, and that when revolving at 95 to 96 r.p.m. the clutch slipped at 51.8, 54.0, and 52.9 b.h.p. respectively. When the wedges were tightened up one half turn further, it required a maximum of 114 lb. to throw the shifter lever in by screw power. When running at 95 r.p.m. the clutch slipped when transmitting 79.9 h.p. After the test, it required a maximum of only 80 lb. to throw the shifter lever in by screw power.

36 Comparing the tests of these clutches, with four arms and two arms, the wedge nuts being turned up three and one-half turns in both cases, the horsepowers required to slip the clutch were found to be 124.8 and 52.9 (average of 51.8, 54.0, 52.9). This would seem to show that the two-arm clutch transmitted only 44 per cent as much power as would the same clutch with four arms for the same adjustment of the wedges. As the axial thrusts, however, were in the same proportion, 103 to 45, it would seem as though the horsepowers transmitted were directly proportional to the number of arms, whether two or four, and to the forces required to throw the shifter lever in by screw power, and therefore to the axial thrusts. No tests were made with six-arm clutches.

CONCLUSIONS

37 Applying the deductions of Tests L, Table 2, to Tests F, Table 4, we may say

A That at 100 r.p.m., with the shoes properly burned in and the wedges adjusted so as to give equal pressures between each of the eight shoes and the ring, and with no excessive lost motion between the jaws and their guides in the clutch-arm casting, a 24-in. four-arm solid clutch and ring will probably break:

a When transmitting 200 h.p., if gradually applied.

b When attempting to pick up a load exceeding 110 h.p.

B That to do so will require:

a A maximum force of between 100 lb. and 115 lb., applied at the shifter lever for a leverage of five.

b A maximum axial force or thrust on the collar of between 500 lb. and 600 lb.

c A combined maximum pressure of the eight shoes on the clutch ring of between 7500 lb. and 8000 lb.

d An intensity of pressure of about 50 lb. per sq. in. for each of the 20 sq. in. of each of the eight shoes of the four-arm clutch.

C That any inequality or lack of evenness and uniformity of the pressures with which opposite shoes bear on the ring, or any lost motion between the various parts, will decrease the breaking strength of the clutch.

D That a 24-in. four-arm split clutch will probably break when transmitting between 150 and 160 b.h.p. at 100 r.p.m., if the force is gradually applied and under proper conditions.

E That the factor of safety of 10, as used by the clutch manufacturer in this case for the solid clutch, is quite ample.

DISCUSSION

I. J. SMITH. The author gives three methods of making friction tch tests:

a Static test to determine the force required to cause the clutch to slip with a given force on the shifter lever.

b The clutch in motion with the load gradually applied.

c The clutch in motion with the load suddenly applied, to determine the pick-up load capacity of the clutch.

While the first two methods are interesting, the results do not ply directly to actual working conditions. The pick-up test alone termines the capacity of the clutch and its factor of safety. Both perience and the results of numerous tests show that the pick-up ad is extremely variable, depending on the class of work. In some stances in actual practice it is more than 210 per cent above the rmal running load of the clutch. From this it is evident that both the rating and in the selection of a clutch for a given service, the ck-up load is the controlling factor.

When a clutch under test has its load gradually applied, the transmitting capacity of the clutch is at its best, and its factor of safety highest. When called upon to pick up a dead load suddenly, the effect on the clutch is that of impact, and the factor of safety is reduced very often to a dangerous degree.

It will be seen from Tests I in Table 1, the only recorded tests upon a split clutch, which is the weaker type of construction, that with a gradually-applied load the clutch transmitted 146 h.p. and broke. The stronger construction—the solid clutch—carried 187 h.p. and broke. Now note that this latter solid clutch carried only 102 h.p. on a suddenly applied, or "pick-up" load, and broke.

On the basis named by the author for gradually applied loads,

TABLE 6 TESTS ON 24-IN. POSITIVE ACTION HILL CLUTCH CATALOGUE RATING 48 H.P. AT 100 R.P.M.

Number of Test	Thrust on Collar, lb.	Maximum Brake Load, lb.	Horsepower at 100 r.p.m.	Remarks
1	258	540	74	Clutch slipped
2	334	830	113	Clutch slipped
3	410	880	120	Clutch slipped
4	544	1030	141	Limit of Testing Stand

that the four-arm split clutch will carry 78.5 per cent of the breaking load carried by the four-arm solid clutch, the split clutch would have broken on a pick-up load of about 80 h.p. This is in line with extensive prony brake tests made by me in 1908 and 1909, which showed for pick-up loads that 80 h.p. at 93 r.p.m. is about the rupture capacity of 24-in. split clutches and about 100 h.p. for 24-in. solid design clutches, as made by different manufacturers.

I must, however, take exception to the author's final conclusion that a factor of safety of 10 exists in clutch manufacture. This is far too high. In the first place the coefficient of rest is greater than the coefficient of motion, and we must not forget that the transmitting capacity of a clutch is dependent upon its ability to pick up its load from rest. In practice the dead load of the prony brake is replaced by the friction and inertia of large masses, such as occur in starting into motion long lines of shafting, flywheels, pumps, attrition mills, ball mills, tube mills, or other similar machinery.

During the time of slippage under the pick-up loads the coefficient of friction is lowest and the wear on the wood shoes greatest.

ce in motion the friction of rest, which exists between the clamped mbers of the clutch, insures the continued transmission of any load at can be picked up.

In the second place the rating of a clutch of any size should based on the split construction. In the test under consideration e rupture capacity of the 24-in. split clutch is about 90 h.p. at 100 p.m. The rating of the makers is 19 h.p. at the same speed. The ctor of safety, therefore, is less than five.

In all tests made by me the final rupture occurred at the key-ay of the clutch hub; the bolting lugs and bolts gave way at the me moment and the ring was broken only by the thrust of the broken utch mechanism.

There is no doubt that the transmitting capacity of a clutch

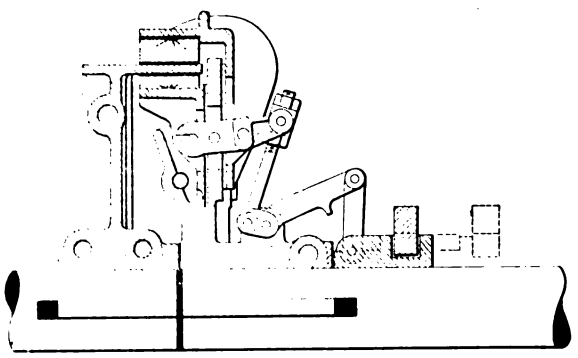


FIG. 4 24-IN. NO. 60 HILL SPLIT CLUTCH (SMITH TYPE)

ncreases practically in proportion with the number of arms; on he other hand it is equally certain, from a study of design, that the actor of safety will vary with the number of arms. My own opinion f the factor of safety of a Hill clutch of four-arm construction is that ach arm, independent of the others, should be able to carry safely he rated capacity of the clutch at 100 r.p.m. This gives a factor f safety of four. For a three-arm clutch in the same manner the fac-or of safety is three, but for a six-arm clutch it rarely exceeds four. This is because a six-arm clutch has a no stronger hub construction han a four-arm clutch on account of the congested design.

In a series of tests by Prof. R. G. Dukes of the Case School of Applied Science, Cleveland, results were obtained upon the ultimate apacities of different types and makes of clutches. In Table 6 s given the performance of a 24-in. split positive-action Hill

clutch, which, however, was not pushed to its greatest capacity on account of lack of power on the testing stand.

To illustrate the enormous power-transmitting capacity of the ring type of clutch, the following test is of interest. It was made on a 24-in. No. 60 Smith type Hill split clutch of very heavy construction. It is rated at 60 h.p. at 100 r.p.m. Fig. 4 shows the design of the clutch, which is positive in its action, no springs being required for disengaging the jaws.

The test was conducted as follows: The power transmitted

TABLE 7 TESTS ON 24-IN. NO. 60 HILL SPLIT CLUTCH (SMITH TYPE)

CATALOGUE RATING 60 H.P. AT 100 R.P.M.

NUMBER OF TEST	THRUST ON COLLAR, LB.	NET MAXIMUM BRAKE LOAD, LB.	HORSEPOWER AT 100 R.P.M.	REMARKS
1	188	365	58	Clutch slipped on further tightening brake
2	258	527	84	
3	312	728	116	
4	380	878	140	
5	456	1087	173	
6	740	1430	228	Limit of testing stand

Prony Brake Arm 100 in. long.

was measured by a prony brake and platform scales. The speed of the clutch shaft was maintained at 93 r.p.m. A spring scale measured the force applied to the hand lever. The wood shoes were first worn to a fit on the ring. Then the jaws were adjusted so that a certain pressure on the hand lever engaged the clutch. Next the brake band was tightened and the clutch engaged, forcibly picking up the dead load from rest. Repeated trials gave the maximum brake load which the clutch would pick up without slipping. When a slip occurred the jaw adjustment was increased to give larger hand lever scale readings, and corresponding higher brake readings. The final reading of the transmitting capacity was limited only by the available power. The results are given in Table 7.

It will be noted that these results were obtained with a split clutch starting from absolute rest—the true pick-up load—and bringing up to speed at the stated loads. No breakage occurred. It is the result of correct toggle action and rigidity of construction.

It is of interest to note also that the ring type clutch described in the paper was the invention of Harry W. Hill (February 10, 1885).

s fundamental construction two members are required: a toggle-
ed friction clamp and a friction ring. To preserve the balance of
clutch and increase its capacity, additional friction clamps are
ed, making two, three, four or six-arm clutches.

. N. VANDERHOEF. The real point in connection with friction
ches is undoubtedly the picking-up of the load, and these tests
n to lack in that they do not give the mass that is started from rest
the time required to accelerate it to uniform velocity. That is
duty the clutch has to perform and is the real measure of the
ngth of the clutch. The time should be given in seconds, or in
tions of seconds. When this is done we will have some idea of the
tive value of friction clutches.

I. J. SMITH. In regard to the time element in tests of friction
tches, I know that in Professor Duke's report and in the tests I
ducted myself, it was found best to throw in the clutch just as
idly as possible. In any case, on a pick-up load, clutches of all
es were thrown in as quickly as it could be done by the impulse
two men on the hand lever.

E. P. HAINES. In connection with the time taken to start a load,
e the case of a gas engine in a machine shop. If the clutch is thrown
quickly, the gas engine will stop, and if it is thrown in too slowly,
clutch will burn out unless it has ample surface to prevent over-
ting. The time taken to apply the load should be between the
o extremes.

H. J. SMITH. Through this system of testing I have evolved the
lowing rules: for single-cylinder gas engines, use a clutch of double
capacity at a given speed; for double and triple-cylinder gas
gines, use one rated at from 25 to 50 per cent above the capacity
sired; with engines of four or more cylinders, use a clutch of the
ed capacity for steam engine practice.

OBERLIN SMITH said that clutches should always be thrown in as
ickly as possible, especially if they have wooden or fiber shoes,
cept where gas engines are used for power. He has found that
tches as a rule are built too small in diameter, necessitating severe
amping to obtain sufficient friction to carry the load. This is some-
nes necessary where the diameter must be restricted, but in general

large diameter should be employed to obtain speed and to reduce the pressure on the clamps. He stated that his experience had been mostly with clutches used for starting presses, where the inertia of large shafts and heavy chains of gearing impose severe strains on them. Under such conditions the clutch surface is run at the highest safe speed, about a mile a minute, in order to obtain the greatest benefit from the friction.

Many of the friction clutches in the market are excellent but complicated. They require a great deal of mechanism to give enormous pressure at the friction surface. For driving heavy presses a much simpler form of clutch is preferable and the old cone form has been adopted. By making the surface wide and large in circumference a very simple toggle mechanism is sufficient.

THE AUTHOR. In reply to H. J. Smith's remarks, I would say that every one is aware that a split pulley is not as strong as a solid one, and for that reason the number of split friction clutch-couplings sold is probably less than ten per cent of the number of solid ones made and sold.

In reply to Mr. VanDerhoef, it should be said that the mass that was started from rest is shown in Fig. 2. The 48-in. by 24-in. brake pulley weighed about 2800 lb. No automatic and autographic apparatus was available for recording the time required suddenly to apply the load. The instructions were to throw the load on as quickly as possible, and this was done. To describe this action as accurately as possible, it is called in Table 5 a suddenly applied load rather than a pick-up load. Just what fraction of a second this was each one can judge from his own experience. The term pick-up load is quite indefinite as to the time element and simply describes the starting into motion of a shaft, etc., which was at rest and with an indefinite amount of slipping of the friction members.

Replying to Oberlin Smith, I would say the intensity of pressure of the shoes on the ring was about 50 lb. per sq. in. with this clutch (see Par. 37 *Bd*).

No. 1288

AN IMPROVED ABSORPTION DYNAMOMETER

By C. M. Garland, Urbana, Ill.

Member of the Society

In testing prime movers, the engineer often laments the dearth of efficient power-absorbing apparatus. Especially is this true in the testing of small high-speed machines, such as automobile engines and steam turbines. In many cases the number of machines to be tested is large, in fact in some instances each machine is given a b.h.p. test before leaving the factory; and in every case where a high degree of reliability is essential from the output, the percentage of machines undergoing test must be large. The attention of the writer was forcibly called to this need several years ago in the testing of a small steam turbine running at 2500 r.p.m., and through this experience the type of apparatus described below was designed and has been used with satisfactory results.

In the design of such a piece of apparatus, the following points have to be considered. These are enumerated in the order of their supposed importance.

a It should be free from binding or "seizing."

b It should be free from producing changes in the load, due to changes in the apparatus itself, such as change of temperature, wear or friction of parts, etc.

c It should be capable of absorbing and accurately indicating a wide range of loads, from zero to the full capacity of the machine.

d The regulation of the load should be positive and instantaneous.

e The apparatus should require a minimum amount of attention and be capable of continuous service.

f It should be self-contained, occupy a small amount of floor space, and be free from noise and the splashing of oil and water.

Presented at the Spring Meeting, Atlantic City, 1910, of The American Society of Mechanical Engineers.

g It should be capable of being quickly changed from one prime mover to another.

h It should require a small amount of cooling water.

3 In considering the above items, it will be noted that Items *a* to *b* practically eliminate mechanical-friction apparatus from the field while Items *b*, *c* and *d* practically eliminate machines depending upon the friction or resistance of liquids for their operation. With these two classes of apparatus removed, there remained only the principle of magnetic induction for the construction of an efficient absorption dynamometer.

THEORY

4 From this principle we know that a conductor revolving in a field of variable magnetic intensity has an electric current induced

FIG. 1 MAGNETIC ABSORPTION DYNAMOMETER

in it. The reaction of this current upon the field that produces it causes a torque between the conductor and the field. There are two ways of dealing with the current induced in the conductor.

ɜ current may be collected by a commutator or slip rings and off from the machine; in the other, the current, or rather s, generated in the conductor may be allowed to remain, and, ing in the paths of least resistance, they will ultimately short- among themselves and produce heat.

ı the first case, we have simply a dynamo mounted in a cradle. rves as a very efficient and satisfactory type of dynamometer. are, however, objections to its use. The currents generated e taken care of either by water rheostats or lamp banks or in the performance of work. Water rheostats and lamp banks considerable attention and occupy space. Owing to the irregu-

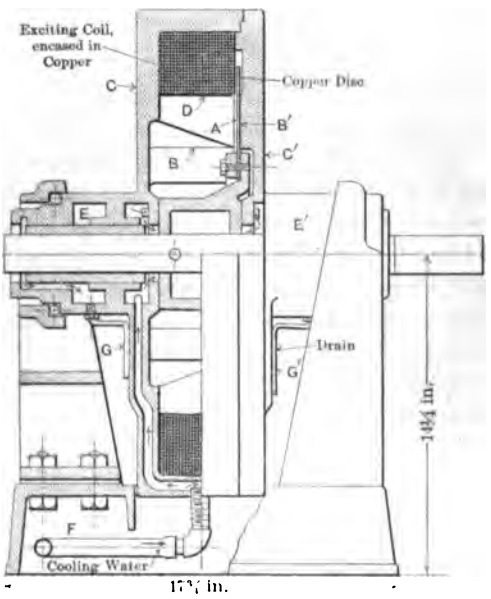


FIG. 2 END ELEVATION AND PART SECTION

in the testing, the utilization of the current for the performance t is in most cases impracticable. The initial cost of a testing this type is necessarily large.

f the currents in the conductor are permitted to short-circuit lves, the conductor is heated; the amount of heat produced is ent to the work absorbed by the dynamometer; and the heat nerated may then be carried off by cooling water. This is the le utilized in the design illustrated, a description of which fol-

DESCRIPTION

7 In brief, the dynamometer consists of a metallic disc revolving between a set of pole pieces so constructed as to produce a magnetic field of variable intensity. Fig. 1 shows the front view of a machine designed to absorb 45 h. p. at from 1200 to 1500 r.p.m. Fig. 2 is an end elevation and part section showing the construction of the dynamometer. It will be seen from this figure that it consists of a copper disc A, mounted on a bronze hub and revolving in front of pole pieces BB'. The magnetic circuit is made up of the casting C, the air gap and the cover plate C'. The castings C and C' are bolted together and carry

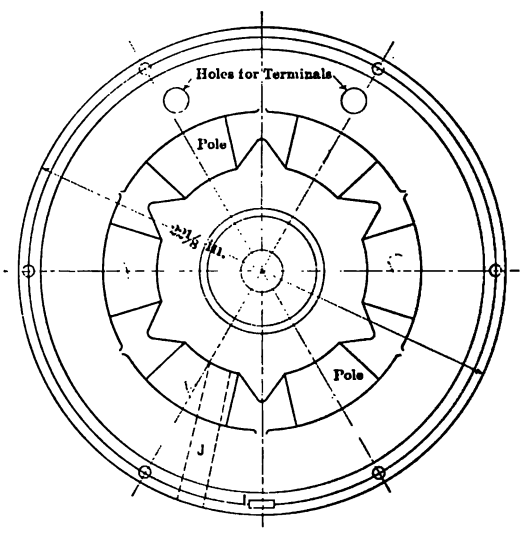


FIG. 3 LEFT HALF OF FIELD CASTING SHOWN IN SECTION IN FIG. 2

the exciting coil D and the bearings E and E'. The magnetic yoke, made up of castings C and C' carrying the field coil and disc, is supported in ball bearings, and is prevented from rotating with the disc by the spring balance shown in Fig. 1. This latter measures the pull or torque between the rotating disc and the stationary yoke.

8 The magnetizing coil is encased in copper, the terminals being carried out through holes in the casting C, which are carefully sealed after the coil is in place.

9 The heat generated by the short circuiting of the eddy currents generated in the copper disc, is carried off by the cooling water which

ters through the base connection at *F* (Fig. 2) and passes up through e bearings into the field casting. It then passes out through opengs which are not shown in the illustration. This water not only rries off the heat generated, but serves as a lubricant for the beargs. That which passes through accumulates in the central chamber , and is discharged at the base of the machine through the drains *G'*.

10 Fig. 3 is a detail drawing of the left half of the field casting *C*, own in section in Fig. 2. It will be seen that there are six poles in ne machine. The circulating water enters at *I* and leaves through he port at *J*. Similar ports are provided in the cover plate *C'*, Fig. 2.

OPERATION

11 In operating, the engine under test is directly connected to the ynamometer shaft by means of some form of flexible coupling, the ooling water is turned on and the engine is started. After normal peed is reached, the load may be thrown on by energizing the field oil. The amount of current and consequently the torque or pull on he spring balance is regulated by a rheostat connected in series with he coil. After running a few minutes, the quantity of cooling water s adjusted so that the temperature of the machine does not exceed 150 leg. fahr. In larger machines the coil may be wound with asbestosovered wire and the temperature permitted to reach 212 deg., so that he cooling water is evaporated within the dynamometer. This educes the quantity of cooling water required about 75 or 80 per cent.

12 The normal working temperature having been reached, the oad on the machine remains absolutely constant, provided the line oltage is constant; for the mechanical friction, which is the bearing riction of the revolving disc, is small and practically constant and hanges in temperature due to changes in the supply of cooling water lso affect the load on the dynamometer very little. The regulation by the rheostat is instantaneous and positive. When the dynamometer is driven by a smooth-running engine, the torque as indicated by the spring balance will not show a variation of $\frac{1}{8}$ lb., while the balance is sensitive to less than $\frac{1}{16}$ lb. This indicates an accuracy that is not necessary even in the most refined testing work.

RELATION BETWEEN SPEED AND TORQUE

13 In the case of the present machine the torque is almost pro-

portional to the speed and is maximum at about 600 r.p.m. From this point the torque drops off about 15 per cent at 1200 r.p.m., and remains almost constant from 1200 to 1500 r.p.m.

14 The torque depends upon the speed, number of poles, thickness of air gap, thickness of the copper disc, shape of the copper disc, and shape and spacing of the pole pieces. By varying the number of pole pieces, and the thickness of the copper disc, the point of maximum torque on the speed-torque curve may be shifted anywhere from 25 r.p.m. to 2500 r.p.m.

CONCLUSION

15 This type of dynamometer is well adapted either for the testing of high-speed motors with a wide variation in speed, such as the automobile engine, or for the testing of slow-speed apparatus having a small variation in the speed. It can be built in practically any size from 10 h.p. up. The principal disadvantage is the high initial cost, although this is not an item where serious and continuous testing work is going on, as in factories or in the laboratories of technical schools, for the labor saved and the increase in capacity resulting through the use of the machine will in a short time more than pay for the initial outlay.

16 The efficiency, which may be expressed as the ratio of the energy absorbed by the dynamometer, minus the energy supplied to the exciting coil, divided by the energy absorbed by the dynamometer, may be made anything up to 99.9 per cent and depends upon the weight of copper placed in the coil. Ordinarily the efficiency is made about 96 per cent, or 4 per cent of the power absorbed by the dynamometer is required in the form of electrical power for excitation.

DISCUSSION

C. M. ALLEN. This paper describes a unique and interesting form of absorption dynamometer, but practically all of the claims brought out in the paper are applicable to and descriptive of the Alden absorption dynamometer. The Alden absorption dynamometer never binds or seizes if it is properly set and operated, and with the automatic valve attached, the internal friction, temperature, wear, etc., have no effect on its keeping balanced steadily, holding the load constant for an indefinite period of time. It accurately indicates the load from full capacity practically to zero, merely the friction of its bearings is

ıdicated, and I do not see why the dynamometer described in this aper would not have the same amount of initial load. The regula- ion of the load on the Alden brake is positive, and although not nstantaneous in its true sense, the full load can be put on or off as uickly as the valve can be opened or closed. The Alden brake also equires very little attention if properly set up and operated. The utomatic valve entirely does away with any hand manipulation, keeping the load constant for hours without any attention. For a given amount of horse power, the Alden brake probably takes up as little room as the one described in this paper, because the brakes can be made with multiple discs. They run as quietly as any ordinary oil bearing and are as free from splash of oil and water. They are also readily changed from one prime mover to another. They can either be mounted on a portable stand, as the one described in this paper, or they can be put on the overhanging end of the engine shaft. The amount of cooling water ordinarily used would be a little greater with the Alden brake than in the electrical dynamometer described in order to keep the temperature of the machine lower for the best operation; but for small machines running at high speeds, it is perfectly feasible to run the cooling water hot enough to make steam.

We have used Alden dynamometers in the laboratory of the Worcester Polytechnic Institute for a good many years, ranging in size from discs 6 in. in diameter up to 34 in., in horse power from $\frac{1}{100}$ up to 150, and in speed from 0 up to 3000 r.p.m., and we are convinced that they are reliable, accurate and comfortable machines to work with. These brakes have always done the work demanded so exceptionally well that the writer has taken up the testing of large water-wheel units after installation. Further particulars concerning the action of these large dynamometers are given in the paper on The Testing of Water Wheels after Installation.[1]

The Alden dynamometers are used extensively in a large number of engineering schools of this country and abroad. They are also used by a great many of the largest automobile manufacturers in this country for testing their engines before installation in the cars, and in some cases after installation by connecting a dynamometer to each end of the rear axle.

These remarks concerning the Alden dynamometer are entirely unnecessary for those who are familiar with it, but were written for the benefit of those who are still looking for a reliable and accurate prony brake.

[1] Trans., vol. 32, p. 275.

THE AUTHOR. I am very glad that Professor Allen has broug
the advantages of the Alden brake as compared with those cl
for the dynamometer described in my paper. The Alden dy
meter fulfils very nearly the specifications outlined for the ma
dynamometer. However, I believe that the latter has the a
tage of requiring less attention and about one-tenth of the wei
water, or in some cases much less; also of the elimination of mech
friction which renders seizure of the rotating with the stationary
a very remote possibility. While this is well taken care of in the
brake, yet if the temperature of the water rises so that the lubri
oil becomes less viscous between the discs there is always presen
danger. I further believe that the regulation or the changing
load requires a greater amount of attention. The magnetic
mometer, if properly constructed, operates as steadily as an el
motor and is, without doubt, the ideal machine in so far as oper
is concerned.

No. 1289

THE MEETING IN ENGLAND

COUNT OF THE MEETING OF THE AMERICAN OCIETY OF MECHANICAL ENGINEERS WITH THE INSTITUTION OF MECHANICAL ENGINEERS

Birmingham and London, 1910

By Dr. F. R. Hutton, Honorary Secretary

and

Calvin W. Rice, Secretary

The American Society of Mechanical Engineers

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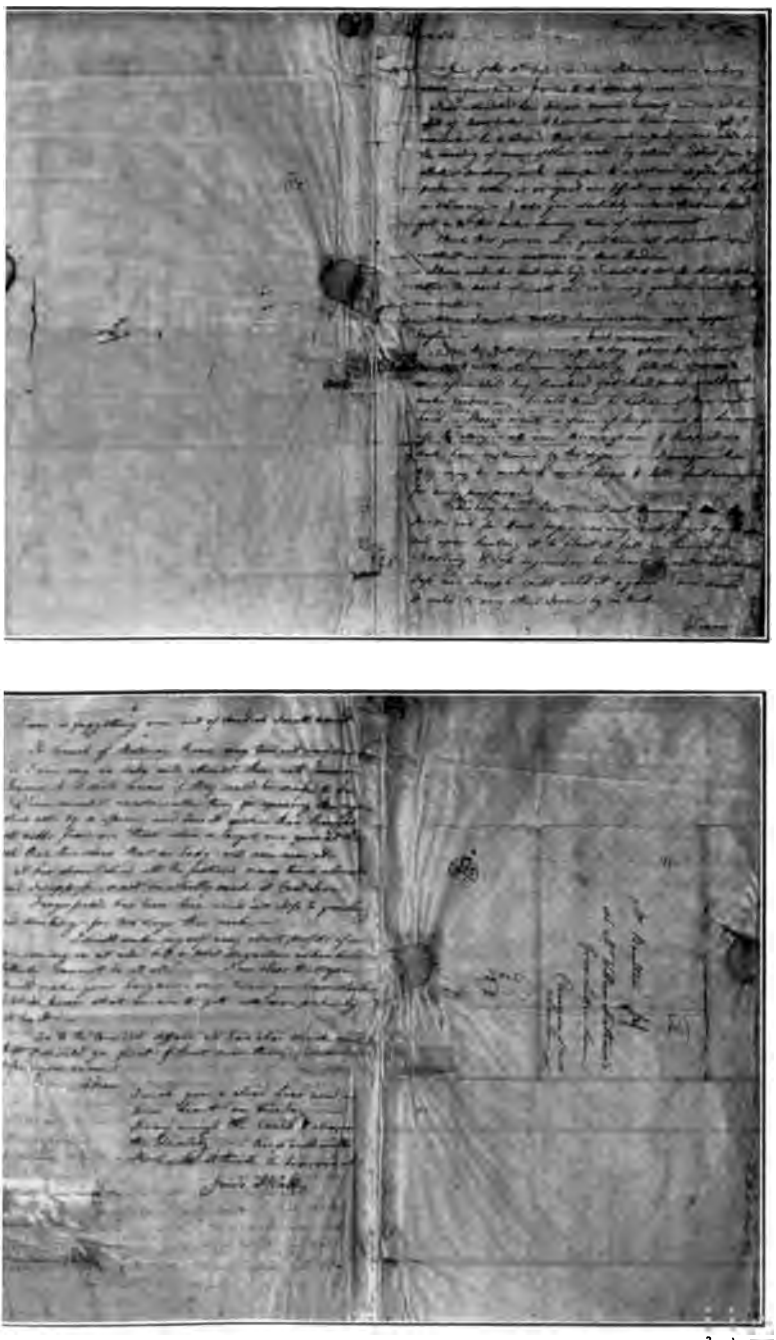

ITT LETTER PRESENTED TO THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS BY MR. GEORGE TANGYE IN BIRMINGHAM, JULY 26

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THE SIGNIFICANCE OF THE ENGLISH MEETING

REPORT BY DR. F. R. HUTTON, HONORARY SECRETARY
The American Society of Mechanical Engineers

It may not be known to all the members of the Society that its Secretary and its Honorary Secretary were made appointees to the meeting of the American and British Societies of Mechanical Engineers in Birmingham, England, in July 1910. It seems therefore proper that something of an official report should be presented from these officers respecting that meeting. The Secretary is to report in full upon the outward and visible elements of the meeting; there is left for the other officer to report at your request upon some of the inner and therefore perhaps broader significances of such a gathering.

These would appear to be three-fold: first, to the members of the American Society participating; second, to the American Society as a whole; third, to the members of the British Society, and to the engineering profession as a whole.

To the members of the American Society participating, it is superfluous to speak of the personal pleasure of the trip. The ocean voyage was a yachting party of congenial friends with every appointment of luxury at their service. The sojourn in England was a house party or week-end visit at a hospitable manor-house, whose hosts could not do too much to keep their guests busy and interested while the beauty and historic stimulus of the Midlands were present as a background for every excursion. But besides this, so intimate an association for twelve days means the changing of acquaintances into friends. The shared memories are bonds which will not easily break; and the Society, made up in some cases of competitors in business who are now personal friends withal, is the stronger for the meeting of 1910.

The significance of the English meeting to the American Society as a whole is in the compliment paid to the visitors by the hosts in and around Birmingham and London in according to American engineering the standing of which such courtesies are the

evidence. It dignifies a body of visitors when the scale of their reception is an indication that they are regarded as being "worth while." The reception by city officials on landing, the courtesies of the Lord Mayor of Birmingham, and the civic splendor of receptions at the Mansion House and in the City Gardens at Birmingham, do not pass to inconsequential outsiders. The whole profession is helped upward and forward by an atmosphere such as this.

In the third place the meeting should be memorable to the British Institution and to the profession at large, because of the topics selected for the American papers, the manner of their presentation and the quality of the discussion on them, and the representative character of the American delegates. The whole participation in the duties of the meeting by the official party was creditable and distinguished. Its influence will be favorably felt for many days.

It was the privilege of the Honorary Secretary in the regretted absence of the President of the Society to respond by request of his associates to the toast of The American Society of Mechanical Engineers at the great banquet in London with which the meeting closed. The sentiment was proposed by Sir William H. White, Past-President of the Institution. The substance of the speech of reply was forced upon a plane of dignity and earnestness by the proprieties of the occasion. Its leading features were:

That any event falls in the class of memorable or of commonplace happenings according as its inner or spiritual meaning is elevated or ordinary. The gathering at Runnymede was but a seditious uprising, unless we see in it the dawn of the philosophy that government is only stable when it secures the greatest good to the greatest number, the principle underlying the triumph of enlightened democracy in America and of constitutional government in England. The death of the Stuart Charles is but an insurrection and an assassination, unless there is seen behind it the lesson that no king "liveth unto himself." Here a tribute was paid to the self-sacrificing industry and devotion of King Edward VII for whom the land was then in mourning.

What were the significances of this English Meeting? Certainly threefold. There was first the fact that visitors from the United States were guests of the mother-country. Why does the American regard Old England as his home-land, even if he were not of English descent? It is more than the common language which underlies this; for many Americans have the languages of Europe as their own and the open doors to the literature of the Continent. The reasons

seem deeper in philosophy and sentiment. To use a figure to bring out the thought, the civilizations of the world may be viewed as structures standing like pyramids on a plain. Research below the visible phenomena will show that the existing civilization has beneath it the customs of the people; below the customs and laws of the people are the conduct and examples of the individual units who make up the people. The source and origin of this behavior are the ideals and inspirations in the soul of the man, having as a rule their basis in his concept of his relation to a personal God or great spiritual first cause. Now the reason the American and the Briton are so near each other and understand each other so well, is that on the courses of the foundation of our respective civilizations where you come to the deep levels of the ideals and inspirations of conduct, the two nations are at one. No one but a sharer of our ideals could have made us tingle and thrill as we do under the spell of Kipling's Recessional; no one but an Englishman could have moved us as he who describes the self-immolation of the noble physician in the Bonnie Briar-Bush; no poet but an English one would have conceived that splendid ideal of a manly death at "Twilight and evening star," and "one clear call for me," with its hope to meet a "Pilot at the bar, when we put out to sea." The Americans rejoice to be the guests of men, sharers of our ideals.

But the English Meeting is not alone of Americans and English, it is of engineers, American and English. Our data of science are the same; the equation of the parabola, or the exponential expression for the expansion of steam under adiabatic assumptions are not changed as we cross the Atlantic. Why then the stimulus each feels in rubbing shoulders with the other? It is that economic conditions and the conditions of industrial production are different in the two countries. With the American the trend of successful production is in the direction of standard product as against special designs. In other words we seek to induce and persuade the buyer to adjust himself to such standard, rather than to have the buyer compel the seller to make special designs to meet a requirement which was in most cases somewhat accidental and not unmodifiable. In economic terms, the American plan is to have the seller write the specifications; the English plan is to have the consulting engineer for the buyer write them. This difference explained American successes in recent competitive history, and threw a strong light on one phase of the "American peril." When the Briton woke up to the advantages of the other system, the days of certain supremacies would be numbered.

In the third place, this meeting was the successor of other transatlantic interchanges, beginning in 1889, repeated in 1893, 1900 and 1904 when the Institution came to Chicago and St. Louis for a visit; and to this last the present meeting, was, in the speech of the national sport, the return match or home game.

Finally, did such a reunion of the great productive engineers of the English-speaking peoples, rejoicing in the same high ideals impose on the two bodies any responsibilities and obligations. Doubtless many, but at least one. The duty of the designer of machines and the manager and director of works to safeguard his work-people at their occupations, that useless and unnecessary loss of life or limb or wage-earning capacity was not entailed where it could least be borne. The air of America was vibrant with the sense of duty to prevent accident in factory and shop; and this was first the duty and opportunity of the trained mechanical engineer. To paraphrase the historic vision of the first violent death in our race: when Cain the older brother, the leader of men, the employer by temperament and gifts, shall be asked, "Where is thy brother? The voice of thy brother's blood maimed or slain in a factory accident crieth out from the ground," the enlightened sentiment of all of worthy ideals will not allow him carelessly and indifferently to answer, "Am I my brother's keeper?" The mechanical engineer is responsible before the bar of the highest justice for any industrial accident which he could have prevented and did not interest himself to forestall. Let us see to it that this sin is not laid to our charge.

THE PROCEEDINGS OF THE ENGLISH MEETING

REPORT BY CALVIN W. RICE, SECRETARY

The American Society of Mechanical Engineers

In the Spring of the year 1909, Sir Robert Hadfield, a member of the Council of The Institution of Mechanical Engineers, brought to The American Society of Mechanical Engineers, on one of his frequent trips to America, the first intimation of a meeting to be held in England the summer of the following year. This was confirmed in September by the following formal invitation from our sister organization:

THE INSTITUTION OF MECHANICAL ENGINEERS

Storey's Gate, St. James Park, Westminster, S. W.

17th September, 1909.

Dear Mr. President:

At a Meeting of the Council of this Institution held today, the following Resolution was unanimously passed:

"That a very hearty invitation be sent to The American Society of Mechanical Engineers to participate in a Joint Meeting in England with the Institution of Mechanical Engineers, and that the Meeting be held in the Summer of 1910, if possible during the last week in July."

I need scarcely say how warmly the subject was supported by those present, especially as the Council had learnt from the Committee appointed to confer with Mr. H. deB. Parsons, the special representative of your Society, the cordiality with which the idea had been taken up by your Members.

We hope that we may be favored with the presence of yourself, your Council, and many of your Members at the proposed Meeting.

With all good wishes, we are,

Yours very truly,

JOHN A. F. ASPINALL
President

EDGAR WORTHINGTON
Secretary

To The President
The American Society of Mechanical Engineers
29 West 39th Street, New York, U. S. A.

Former gatherings of a like nature had taught not only the value, also the great pleasure to be derived from such a meeting of the national mechanical engineering organizations, and by the unanimous vote of the Council of the Society the following reply was patched:

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
29 West 39th Street, New York, U. S. A.

ar Mr. President:

The Council of The American Society of Mechanical Engineers has considered the very cordial invitation of The Institution of Mechanical Engineers, old a joint meeting in England in the Summer of 1910, conveyed by your letof September 17.

The Council was unanimous in the acceptance of the invitation and bids me vey to you its action as follows:

Resolved,—That The American Society of Mechanical Engineers accept very cordial invitation of The Institution of Mechanical Engineers, to hold int meeting in England in the Summer of 1910. The Council feels that the rests of Engineering throughout the World will assuredly be advanced by giving and the acceptance of this invitation;—an evidence of an increasing peration among the various societies representing the Profession of Engiring."

n conveying this resolution of the Council permit us to inform you of the versal cordiality with which the invitation has been received both by the ncil and by the Members of the Society. It is the expectation that a repretative delegation of the Society will be present at the meeting.

lease accept our expressions of sincere good will.

JESSE M. SMITH
President
CALVIN W. RICE
Secretary

The President
he Institution of Mechanical Engineers
London, England

The preliminary work of announcing this action to the membership s assigned to the Executive Committee of the Council as well as tentative arrangements for transportation, whereby an option, piring March 1, was secured upon the entire first cabin of the White ar Steamship Celtic, sailing July 16 for Liverpool.

The Committee of Arrangements immediately upon its appointnt by the Council in the Spring of 1910 took up the task of perting these and other details, producing, under the able Chairmanp of Ambrose Swasey, Past-President Am.Soc.M.E., a result which ade this meeting an event in the history of the Society.

NEW YORK TO BIRMINGHAM

The Celtic with the official party of 144 members and guests steamed from the White Star dock in the North River at two o'clock in the afternoon of July 16, under a cloudless sky, good augury of the voyage ahead. The Committee on Acquaintanceship which, with the characteristically energetic generalship of Dr. W. F. M. Goss, met immediately after dinner the same evening and remained continuously on duty until the end of the voyage, soon made the individual members of the party known to one another. Invitations, on which was embossed and colored the emblem of the Society, were also issued to the other members of the first cabin, cordially urging their participation in the events arranged for the week on shipboard, a thoughtful act suggested by Professor Hutton and Mr. Brill which was greatly appreciated. The entire group was thus at once brought into a friendly relationship not usually secured until the end of the journey.

The first day out, which was Sunday, was spent quietly in resting and visiting, religious services being conducted by the Right Reverend William D. Walker, Bishop of Western New York. On Monday, preliminary games were begun on deck. In the evening the officers and past-presidents of the Society, together with the officers of the Celtic, received the first cabin passengers on the upper promenade deck, thus bringing the party and the other voyagers into closer acquaintance. This is believed to be the first occasion in the history of the Celtic, if not of the steamship line, in which the officers of the ship participated in receiving the passengers. A dance followed the reception.

The lecture given on Tuesday evening by Worcester R. Warner, Past-President, on What are the Astronomers Doing, was not only entertaining but instructive, and was finely illustrated by lantern views, many of which were new and shown for the first time to any audience.

The musicale arranged for Wednesday evening proved one of the most enjoyable features of the trip, displaying to advantage the versatility of the Society's membership. The success of those in charge in enlisting the participation of the other passengers was exemplified in the acceptance of the chairmanship of the evening by Mr. Everett P. Wheeler, well-known in legal and political circles in New York City. The program follows:

SELECTION	Guglielmo Tell	Rossini
	Orchestra	
VOCAL SOLOS	*a* The Flower Song from Faust	Gounod
	b Ask Me no More	Tosti
	MISS GRACE BURLINGAME	
CELLO SOLOS	*a* Romance	Davidoff
	b Largo	Handel
	DR. LEONARD WALDO	
MONOLOGUE	The Village Dressmaker	Wiggin
	MRS. JESSE M. SMITH	
VOCAL SOLOS	*a* The Skipper of St. Ives	Roeckel
	b Three for Jack	Squire
	D. J. EDMONDS	
PIANO SOLO	Song Without Words	Mendelssohn
	MISS ALICE M. MAIN	
READING	The Limerick Tigers	Edwards
	PROF. F. R. HUTTON	
SELECTION	Three Dances Henry VIII	German
	Orchestra	

ppreciation felt by the first cabin passengers of the enter-ents arranged by the Society was expressed by Mr. Wheeler at nclusion of the musicale.

Thursday evening, John R. Freeman, Past-President, gave an sting illustrated address on the Construction of the Panama , of which it is well known Mr. Freeman speaks with authority gh his official connection with the Board of Engineers appointed esident Taft to visit the canal in 1909. Slides of a different ter were afterward thrown on the screen, showing among other a portrait of Captain Hambelton, and a reproduction of the card of the dinner given by Ambrose Swasey, then President Society, at the time of the last visit of the Institution to ca in the year 1904. As the words of God Save the King were , the audience joined in singing the British national song. y evening was devoted to dancing.

ridge-whist contest was held Thursday afternoon, and on Fri-e sports took place, miscellaneous games being also in progress, the entire week. Saturday evening had been set apart for arding of prizes to the winners of these various tests of skill or a gathering of a more informal nature than those of pre-evenings. Prof. F. R. Hutton presided over the occasion, fter an orchestra had rendered a selection, Geo. M. Brill, Chair-of the Entertainment Committee, announced the following

awards: 1st prize in bridge-whist, to J. D. C. Darrell, a pair of flat brushes in a leather case; 2nd prize, to John Calder, a pigskin traveling case for collar buttons, etc.; 3rd prize, to Mrs. W. K. Carr, a hat pin; 4th prize, to Mrs. M. B. Orde, a bridge set; 1st prize in shuffleboard contest, to Karl Dodge, "Satchel Guide to Europe;" 2nd prize, to Theodore Main, "My Trip Abroad;" to the winner of the pillow fight, H. M. Klingenfeld, a knife on a small pillow; to the winner of the men's potato race, A. Wise, a coin purse; of the ladies' potato race, Miss H. E. Armstrong, a silver coin holder, and Miss Gertrude Baker, a silver pencil; and to the winner of the obstacle race, Karl Dodge, a coin purse. A so-called endurance prize, a fan, was also given to Mrs. Jesse M. Smith, the last lady to stay in the game of shuffleboard. A consolation prize, consisting of a doll, was contributed by friends to Frank B. Gilbreth, who lost in the final round of shuffleboard, and also as a mark of appreciation of his efficient service as Chief of Police in maintaining order during the games. Prof. F. R. Hutton received a loving cup, of the telescopic variety. As each winner came forward to receive his or her prize, a speech was demanded, thus eliciting a number of impromptu remarks which greatly added to the merriment of the evening. Most of these prizes, chosen with characteristic good taste, had been appropriately engraved or stamped with the name of the Society and the occasion, through the thoughtfulness of Mr. and Mrs. Brill.

James M. Dodge, Past-President, followed with a humorous lecture, entitled An Exhaustive Review of the Formation of the Earth and its Oceans, with Some Conclusive Educational Remarks on the Solar System and Prognostications on the Ultimate End of the Universe, in which he assumed to controvert the theories of all other scientists. A jury consisting of Ambrose Swasey, John R. Freeman, William H. Wiley, Oberlin Smith, Jesse M. Smith, George M. Brill, Calvin W. Rice, H. L. Gantt, Prof. W. F. M. Goss, Prof. Arthur M. Greene, Jr., James Hartness and F. H. Stillman, had been chosen to sit in judgment on his arguments and, clad in the robes of office, filed in with due solemnity as Mr. Dodge began his address. Mrs. E. B. Danforth, eighty years of age, then rendered a piano solo, and A. T. Baldwin read the following "Engineer's Reverie," written by Granger Whitney, Superintendent of the Detroit Iron and Steel Company, a member of the Detroit Engineering Society:

WHAT'S THE USE

By Granger Whitney, Detroit, Mich.

's the use of running levels on a hillside that is steep?
's the use of building railroads through the valleys that are deep?
your cantilever bridges, with record breaking spans,
aids to navigation, your ship locks and your dams.
ıe hydrostatic pressure at the Sault, it gives me chills,
he dusty, smoking tunnel running through the Hoosac hills
s me weary with existence; the canal at Panama
ı a labor of utility thats hardly up to par.
Oh—What's the use?

's the use of doubling up your work on multiple machines
ıe weary brain is pinioned to a rack of grasping schemes?
indicator card will show expansion of the head,
ıstion of the intellect, the cut-off finds you dead.
monoplane and gasolene you navigate the air,
differential valve gear drives a man to deep despair,
many new inventions you strive till you obtain
cstatic culmination of an epicylic train.
Oh—What's the use?

s the use of sinking shafts six thousand feet at Calumet?
s the use of stoping out the Colorado sulphuret?
t's conical drum engines and ventilating fans,
the cyaniding process and amalgamating pans,
ı shovels do your digging in a most efficient way,
ındred tons of Bessemer you're smelting in a day.
:onomy and saving with gas seal and double bell,
y-five percent Mesabe and your tops blown all to hell.
Oh—What's the use?

s the use of putting bilge keels on an ocean going ship,
:r roll and let the lubbers seek their bunks or miss the trip.
's forced draft on your boilers, you have sixty feet of beam
ıove with two propellers and a trinity of steam.
twelve-foot center hatches and twelve thousand tons below
your rivets groan and tremble when the wind comes on to blow
days from Escanaba to Conneaut, your goal,
here you fuss and fidget till you're sailing north with coal.
Oh—What's the use?

ı're going to be a pessimist there isn't any use
ilding ships or mining ore or generating juice.
ır ultimate ambition is to roll a ton of rails,
ild an automobile or to make a keg of nails
ill find that life's a burden, you will find existence stale,

If you live by rule and precedent you pretty sure will fail,
And if you only work and sleep and take three meals a day
Why there isn't any answer and it really doesn't pay.
So—What's the use?

It's the friends you've got in Denver, it's your life out on the hills,
It's the men you met at Panama, your record with the drills,
It's the girls you've met on ship board at Harrisburg, the friends you left
at home,
It's that plutocratic feeling when you're hiking down from Nome.
It's the people up in Scranton, it's the folks you met in Lynn,
It's your cronies out in Pueblo, it's the places you have been,
It's the life you led at Phoenix when you crossed the great divide,
It's the work you did at Jarrow, it's your record on the Clyde.

It's the golf you played at Birmingham, your San Francisco spree,
It's when you saw the springtime clothe the hills of Tennessee,
It's the drinks you drank in Pittsburg in your youthful days of joy,
It's that forty mile excursion from Schenectady to Troy,
It's the days you spent in Helena, your luck at Cripple Creek,
It's the gang at South Chicago that never went to sleep,
It's the fellows at Altoona, it's the men that sing and laugh,
It's the men you've known and lived with from Newport News to Bath.

It's when the day is over and your work is all well done,
It's when the campaign's ended, it's when the battle's won,
Then friendship keen, and memory of many happy days
Bring the glorious satisfaction that a life of action pays.
That's the use—That's the use—
And we'll drink a toast to energy and raise a merry song,
We'll lead a life that's strenuous, we'll work a day that's long.
And when that day is ended and our work is damned well done
We'll meet around the festal board, we'll have a little fun.
That's the use.

Ambrose Swasey, Chairman of the Committee of Arrangements, expressed briefly the Society's appreciation of the courtesy and friendliness of the ship's officers, which had added so much to the week's voyage, and as a memento of the trip presented to Captain Hambelton a silver case, beautifully chased and engraved with the words, PRESENTED TO CAPTAIN A. E. S. HAMBELTON, COMMANDING S. S. CELTIC, BY MEMBERS OF THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, JULY 23, 1910; and to Chief Engineer Lapsley an electric desk lamp, with Tiffany favrile glass shade, similarly engraved. These tokens came as a great surprise to their recipients, who expressed their thanks in a few graceful remarks.

sor Hutton brought the program to a close with the following itten by him for the occasion:

AN - ODE; WITH KATH - ODE

By Dr. F. R. Hutton, New York

Honorary Secretary of the Society

THE AN - ODE

There once was a "Gang" transatlantic
Up to all sorts of lark and of antic;
The Celtic's so steady
That each one is ready
For play, spite of sea rough and frantic.

They have heard about comet and star,
In dancing, they've scampered afar,
At the "Tigers" they've smiled,
Been by "Bell-buoy" beguiled,
And learned, too, about Panama.

We have Swasey to act as our Boss,
We have chuckled with Hartness and Goss,
And with Miller, (T. Spencer),
As stunt-scheme dispenser
The trip's end seems much like a loss.

One lad used a big megaphone;
Perched aloft, with a loud brassy tone,
He told us who scored
When they played shuffle-board
With a glee which is just Dodge's own.

One uses a lot of his breath
We all like to hear what he saith:
His nonsense is fine
I wish like it for mine
But can he be "wasting," Gilbreth?

Nor must we forget our police
So great in preserving the peace;
Were "face-making" a crime,
Then "gum-chewing's" sublime,
And grave misdemeanours must cease.

THE KATH—ODE

We seem to be nearing the shore
When our larks for a while will be o'er
But we'll never forget;
And the friends we have met
Will be mem'ries of joy ever more.

So here on our last festal night
And with Ireland almost in sight,
We sing "Hail to the Chief"!
(To Lapsley, in brief)
Who has handled our engines' great might.

But to Hambelton—bless heart and head—
Our last friendly word shall be said:
"Good luck" and "Good-bye,"
We unite in the cry:
From the sea he has lifted all dread.

After singing My Country 'tis of Thee, appropriately followed by God Save the King, the company dispersed amid many expressions of appreciation. During the evening a collection was taken for the Seamen's Charities of Liverpool and London.

The program of Saturday evening, which was characterized throughout by a spirit of good-fellowship, brought to a close the unique and delightful series of events provided by the Committee on Entertainment, to whom as well as to the general committee so much of the pleasure of the trip was due. Indeed too much praise for the perfection of the entire series of entertainments cannot be accorded the Chairman and his committee, who not only followed out various suggestions made by the membership, but so elaborated them as to make the best possible provision for the pleasure of the voyagers. The friendships formed on such a journey, which must remain a source of satisfaction long after the details of the trip are forgotten, and which contribute so much to the welding together of the Society's membership, were, it is needless to say, a feature the importance of which cannot be measured. The greatest regret was expressed on every side at the unavoidable absence of President and Mrs. George Westinghouse. The entire trip was remarkable for fine weather and smoothness and was made comfortable and pleasurable to all by the excellent service.

At six o'clock Sunday evening, July 24, the Celtic entered the River Mersey, where she was met by the White Star tender Magnetic,

ging a deputation from the Lord Mayor of Liverpool and from The tution of Mechanical Engineers. The party consisted of Deputy . Mayor Henry Lea, Esq., a member of the Council of the Insti- on and formerly Lord Mayor of Liverpool; J. A. F. Aspinall, ident of the Institution; Prof. W. H. Watkinson of Liverpool versity, a member of the Institution; Edgar Worthington, Secre- of the Institution; and several others, all of whom brought to American Society the official greetings of the city of Liverpool of the British organization. In the absence of President West- ouse, Vice-President Goss and other officers of the Society ved the guests in the saloon of the Celtic. The Deputy Lord or in a cordial speech regretted the unavoidable absence of Lord Mayor of Liverpool, on whose behalf he bade them wel- e as brethren both in blood relationship and in professional inter-

America, he had found in his own visits to that country, a htful place inhabited by delightful people, and he hoped that and might prove both enjoyable and profitable to the visitors. r. Aspinall then tendered the welcome of the English Institution, h had so long been anticipating the visit of its American brothers. t Britain, he said, was a somewhat acquisitive nation and it hoped that the visitors would leave behind them a great volume od mechanical ideas, and that they would find the visits to British s of as great interest and value as he had found those which he nade in America. In the United States, he understood, university for engineers was ahead of that in Great Britain, and the gradu- rom these colleges were so numerous and energetic that they were ding themselves even over the British colonies.

ofessor Watkinson followed with a few remarks regarding Ameri- olleges, describing his recent visit and the kindly treatment he eceived, and expressing himself as deeply impressed by the magnt equipment and the enormous research work being done. He uded with a cordial welcome from the engineering department verpool University.

gar Worthington, a friend of long standing of the American ty, was also called upon for a few remarks. Mr. Fothergill, senting the management of the White Star Line, made a short h placing the facilities of his company at the disposal of the lers upon arrival.

ese hearty greetings were acknowledged by Vice-President Goss, expressed the gratification of himself and of his American friends, heir keen appreciation of the coming events.

After the welcoming delegation had departed, the Celtic was towed to her dock to remain over night, the party landing in Liverpool the next morning and, after the necessary formalities of the customs, proceeding at once to the Lime Street Station where special dining coaches waited to convey them to Birmingham. President Aspinall of the English society, together with Mrs. Aspinall and their daughters, and also Fred. W. Taylor, Past-President of the Society, and Mrs. Taylor who had reached England some days earlier, were on board the train to greet the party.

At Birmingham, Messrs. Howard Heaton and Fred. M. Lea, Honorary Secretaries of the Local Committee, received the party upon their arrival and escorted them to motor omnibuses which conveyed them to their respective hotels. So thoroughly had the Committee on Transportation, Charles Whiting Baker and the Secretary, done its work that not only had hotel accommodations for each individual been arranged in Birmingham and London, but no one from the time of the departure of the Celtic to the close of the meeting in London, was obliged to concern himself in the least regarding the disposal of baggage.

On Monday evening President Aspinall tendered a dinner at the Queen's Hotel to the Past-Presidents and Council of the American Society, to which were also invited the Council and Past-Presidents of the Institution. The Lord Mayor of Birmingham, Alderman W. H. Bowater, was the guest of honor. There were also present, Dean W. F. M. Goss, Sir William H. White, Sir Oliver J. Lodge, Charles Whiting Baker, Arthur Keen, Ambrose Swasey, Sir Gerard A. Muntz, Bart., James Mapes Dodge, William H. Maw, Jesse M. Smith, Sir George Kenrick, Oberlin Smith, Edward P. Martin, Prof. F. R. Hutton, J. Hartley Wicksteed, Prof. R. C. Carpenter, Joseph S. Taylor, Walter Pitt, J. C. Vaudrey, Henry Lea, Henry L. Gantt, H. A. Ivatt, Robert Matthews, H. Graham Harris, Worcester R. Warner, H. F. Donaldson, William H. Allen, Howard Heaton, Alderman Sir Hallewell Rogers, John R. Freeman, Prof. W. Cawthorne Unwin, Arthur T. Keen, Edgar Worthington, James Hartness, Hon. William H. Wiley, Loughnan Pendred, Mark H. Robinson, Fred. M. Lee, E. B. Ellington, Frederick W. Taylor, F. Dudley Docker, George M. Brill, Michael Longridge, George Tangye, Edward Hopinkson, George Robert Jebb, Capt. H. Riall Sankey Reginald K. Morcom, Godfrey Nettlefold, Dr. H. S. Hele-Shaw, Eric M. Carter, and the Secretary. Toasts were given to the King, the President of the United States, and to the Guests. Respecting the latter, Mr. Aspinall spoke of his gratifi-

cation at the welcome which the city of Birmingham had accorded to the American visitors and of the great regret felt by all at the absence of Mr. Westinghouse, to whose coming all had looked forward, some in appreciation of him as a friend and a splendid host, and all in admiration of him as an engineer known from one end of the world to another. It was most appropriate that the societies should gather in Birmingham where the Institution of Mechanical Engineers was founded in 1847, under The leadership of its first president, George Stephenson, in a hotel of the same name, if not the very building in which this dinner was now held. Referring to the meeting now in progress, it had for an object, he said, not only the study of the work of our brother engineers, but the widening of acquaintance with one another.

Dr. Goss, as acting President, responded to this toast on behalf of the Society, and brief remarks were also made by Ambrose Swasey and other members.

TUESDAY, JULY 26

The meeting was formally opened on Tuesday, July 26, at 10 o'clock, in the Lecture Hall of the Birmingham and Midland Institute. The officers of the two societies who had assembled in the Institute Board Room previous to the meeting, entered the hall in a body at the beginning of the session, and took their assigned seats on the platform. The American Society was represented by Dr. W. F. M. Goss, James M. Dodge, John R. Freeman, F. R. Hutton, Jesse M. Smith, Oberlin Smith, Ambrose Swasey, F. W. Taylor, Worcester R. Warner, Charles Whiting Baker, E. D. Meier, Henry L. Gantt, James Hartness, Wm. H. Wiley, Willis E. Hall, and the Secretary. The Lord Mayor of Birmingham, Alderman W. H. Bowater, heartily welcomed the members to the city on behalf of the Reception Committee, whose chairman, Mr. Neville Chamberlain, was prevented by a slight accident from being present, and expressed the hope that the American visitors would feel when the time came for their departure that they had been treated not as strangers but as members of the same brotherhood. It was very fitting that Birmingham, the birthplace of the English Institution, considered the very center of mechanical engineering, should have been selected for so important a gathering as the present meeting. Some people did not think it a very beautiful city, but its own inhabitants were delighted with the darkness of the atmosphere and the ever-present smoke because the more plentiful the smoke the greater the volume of business in the workshop.

The Lord Mayor was followed by Mr. George Tangye, Vice-Chairman of the Reception Committee, who as custodian of the Boulton and Watt relics, offered to the Society a framed letter written by James Watt in 1777, as a memento of their visit to Birmingham. President Aspinall of the Institution in expressing his own appreciation of this gift by Mr. Tangye to the American Society referred to the close connection between the two nations as illustrated by the fact that Boulton and Watt sold to Robert Fulton his first engine. Birmingham had thus played its part in engineering work on both sides of the Atlantic. Another of its citizens, James Wyatt, invented the first cotton-spinning machine in 1741 and in the city museum, the first hanks of cotton produced by it might be viewed at any time. Engineers recognized, he said, how much they owed to Birmingham and how much the city had done and was doing, not only in scientific advancement by means of their great university, but by the hard-headed constructive knowledge and ability of the people who fought to keep in British hands by the peaceful weapons of commercial conquest a fair share of the world's trade.

Dr. W. F. M. Goss expressed the hearty thanks of the American Society for the welcome accorded them and to Mr. George Tangye for his generous gift. This was the third official visit of the Society to England and previous experience had taught the members how great a privilege it was to be the guests of the Institution. Entering England with a recognition of how many practices of the profession had their beginning here, they were already in full enjoyment of everything found in the country, from the green of the trees and meadows to the permanency and beauty which characterized so many of the engineering structures. Under present-day conditions the engineer had become the world's great civilizer and in the transforming process in which men had been given new occupations and the world of their fathers replaced by a new world, the engineers of England and America had had a large part. National boundaries no longer affected them for, thanks to the English shipbuilders, the ocean between them had become an easy means of communication. The spirit of the two organisations, if not the organizations themselves, might be federated, and to such a result this meeting was sure to prove a contributing factor. Mr. Tangye's generous gift had quite taken them by surprise and they would not forget the giver in their enjoyment of the new possession.

The inscription on the frame of the memorial was then read:

ENTED TO THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS BY GE TANGYE AT THE JOINT SUMMER MEETING AT BIRMINGHAM IN JULY,

Dr. Goss added that the letter was both written and signed by s Watt, and was very legible and well preserved in every re- . A photograph of the letter showing the two sides is given vith. It reads as follows:

Birmingham, May 10th, 1777.

Sir:

ırs of the 8th before me. Salmons man is making wheel engine boiler and to do tolerably well.

ı astonished how Joseph deceived himself and us in his effect of Bow boiler e not seen him since—but I remember he told me that there was a pro- ıs odds in the quality of some of their coals by others. Did you say er pushing in the damper to a certain degree did not produce a better or as ın effect as opening the hole in chimney—and was you absolutely certain o feed got into the boiler during time of experiment.

ink that you are in a good train at Shadwell and recollect no more cautions ıt head.

ve made the best apology I could to Mrs. B. though she talks the words of ; she is in very good humour and all are well.

n I see the table I can reason upon copper boylers.

w the Battering Ram, or devil incarnate, go today above 60 strokes per e and work its own regulators. All the stampers were assembled. They ed God that Webb could not make feaders in. He told them he had one se and in hand. Moore wants a score of large ones for his own use. The s all over Birmingham and I expect we shall have customers by the dozen. ine that they may be made to work forges and tilts fast enough for any ıe.

bury Iron has turned out dammed bad, the piston rod for Huel bussey ry well forged by Dixon and upon heating it to float it fell in two at the ıg and Joss rejoiced in his heart thereat, but not Joss nor Joseph could ; again—nor would it weld to any other iron by no trick.

ın is fagotting one out of Swedish small bars.

branch of Battering Rams may turn out very cursedly, as I dare say no- vill attempt them with common engines, and I don't know if they could le to do. I have invented an admirable thing for opening the regulator acts by a spring and does it quicker than thought. All Webb's fears are hen a larger one goes at the rate that his does, that nobody will come .

s demolished all the fixtures many times already, and I suppose must ılly made of cast iron.

gerfield has been here and sett Joss to growling and drinking for two days eek.

ıuld make myself easy about profits, if any were coming in at all, but a tagnation as has been hitherto cannot do at all. I am clear that you make your bargain sure before you leave London and lett us know what to get with some probably, at least.

As to the Cornish affair. It has also struck me that I should go first and that something should be done before you come.

Adieu.

I wish you a clear head and a firm heart on Tuesday. Pray weigh the coals and observe the quality. Keep well with Rothwell. I think he deserves it.

Yours,

J. Watt.

Mr. Aspinall then took the chair and at his request a telegram of regret was sent to Mr. Westinghouse.

After the transaction of some routine business the following papers were read and jointly discussed, the chair being alternately occupied by Mr. Aspinall and Dr. Goss on this and succeeding days: English Running-Shed Practice, by Cecil W. Paget, Member I. Mech.E., General Superintendent, Midland Railway, Derby; Handling Locomotives at Terminals, Frederic M. Whyte, Vice-President Am.Soc.M.E., General Mechanical Engineer, New York Central Lines, New York; Engine-House Practice, F. H. Clark, Mem.Am.Soc.M.E., Chicago, Ill.; American Locomotive Terminals, William Forsyth, Mem.Am.Soc.M.E., Railway Age Gazette, Chicago, Ill.; and Handling Engines, by H. H. Vaughan, Member I. Mech.E. and Am.Soc.M.E., Canadian Pacific Railway, Montreal, Can. The discussors were George Hughes, James M. Dodge, Henry Fowler, Henry L. Gantt, Arthur D. Jones, J. E. Sague, F. H. Clark, Cecil W. Paget, William Forsyth, F. M. Whyte and H. H. Vaughan.

Tuesday Afternoon and Evening

After luncheon, which through the courtesy of the Lord Mayor, was served in the Town Hall, the visitors scattered to enjoy the various trips to places of professional and historical interest in and about Birmingham, arranged by the local Reception Committee for both Tuesday and Wednesday afternoons. One of these was a trip to Dudley Port, Tipton, where inspection was made of the works of the South Staffordshire Mond Gas Company, under the guidance of the Managing Director, Edmund Howe, Esq., Member I.Mech.E. This company distributes gas for power and heating purposes over an area of about 123 sq. mi., in what may be termed the industrial heart of England. The plant comprises eight producers, each capable of gasifying 20 tons of fuel per day and generating sufficient gas to drive gas engines of 2000 h.p. continuously. Here also the testing station of the Pump and Power Company was visited, which contains four Humphrey pumps of various types, the largest of which is 4-

ycle, delivering 250,000 gal. per hr. to a height of 35 ft. H. A. Iumphrey, Esq., Managing Director, Member I. Mech.E., conducted he party.

Another excursion was that made to the works of the Austin Motor Company at Northfield, under the guidance of H. Austin, Esq., Governing Director, where the range of models manufactured comprises the 4-cylinder engine of the 25 to 30-h.p. type; a smaller model of 18 to 24 h.p.; a 15-h.p. 4-cylinder model in two forms, one having the engine in front and with narrowed frame used for taxicab work, and the other the engine under the driver's seat, used for landaulet or coupé carriages, or light delivery vans to carry loads up to 15 cwt.; a 7-h.p. single-cylinder; a 50-h.p. 6-cylinder; and an 18 to 24-h.p. 4-cylinder of a special type fitted with detachable wire wheels. The works of the company occupy over six acres, one building being devoted to the machine shops, and the other departments being the grinding section, hardening shop, power house, engine test-house, plating and polishing sections, erecting shop, copper and tinsmith's shop, chassis test-house, wheel building shop, finishing shop, pattern-maker's shop, carriage building shop. The restaurant of the company, where the guests had tea, is shown herewith.

A third party, conducted by the Managing Director, Percy Wheeler, Esq., Member I.Mech.E:, visited the Metropolitan Amalgamated Railway Carriage and Wagon Company at Saltley, which covers 20 acres and comprises a smith, smithy power house, steel under-frame shop, machine shop, power house, boiler house, foundry, saw mill, gantry, wagon building shop, car body shop and paint shop. These works are lighted by electricity generated on the grounds and employ about 3000 men.

The Frankley Filter Beds to which a trip was also arranged, are situated near Northfield, and form a portion of the Elan Supply Works designed to furnish eventually 72,000,000 gal. per day. Points of especial interest are the reservoir, filter washing, pure water reservoirs, pumping station, and the mains and meters. The resident engineer, F. N. Macaulay, Esq., acted as escort. On all of these trips tea was served at the works, usually in the employees' mess room, commonly found in English workshops.

An excursion to Stratford-upon-Avon included visits to Shakespeare's birthplace, the Church, the Memorial Theatre, Anne Hathaway's Cottage, and other points of interest. Tea was served at the Shakespeare Hotel. Many of our party were interested in the fact that The Piper, a play written by one of our own country-

women, the wife of one of our members, Josephine Preston Peabody (Mrs. L. S. Marks), of Cambridge, was to be produced for the first time on Wednesday evening at the Memorial Theatre, having been awarded the £300 prize in a world's contest. A number of the members of the Society were present at this initial performance which received much favorable criticism.

A trip was also made to the historic town of Worcester, "The Faithful City," where at the Guildhall the Mayor, Hon. Alfred Percy Allsopp, and the Corporation of Worcester, welcomed the party. At the Cathedral, on the eastern bank of the Severn, the Dean, the Very Reverend Dr. W. Moore Ede, gave a brief historical address, tracing the growth of the group of buildings from their beginning as a small Benedictine Monastery in 680 A.D., through the building period fostered by the Normans in the eleventh century, their vicissitudes under Henry VIII and again under Cromwell, to their final restoration in 1874. This great cathedral of the Western Midlands is simple in plan, and while the restoration has of necessity removed much of the "atmosphere" of antiquity so dear to the American visitor, the interior has a wonderful perfection of design, and gives proof of the most reverent care.

The party also visited the Worcester Porcelain Works which were founded in 1751 by Dr. John Wall, a distinguished physician and artist who succeeded in producing one of the most beautiful of the porcelains and to whom in 1788 King George III granted a patent which gave to Worcester the first royal porcelain works in England; as well as the quaint Hospital of St. Wulstan, commonly called the Commandery, which dates back to the 11th century. The entire place is rich in historical associations, intimately connected with the Civil War, and is full of carvings, furniture and objects of art.

Some of the party also visited Stoneleigh Park where, after a view of the ruins of the old Cistercian Abbey built in the 16th century, the party proceeded to Kenilworth, exploring the Castle and having tea at the Abbey or Kings Arms Hotels.

All of these trips were arranged by the Committee with the greatest care and forethought for the welfare and pleasure of the visitors, special trains or motor buses as well as guides being supplied in every case, and provision being made for both luncheon and tea. On the technical excursions these were furnished through the courtesy of the companies.

Birmingham itself contains so many places of professional interest that many of the guests took advantage of the opportunity to inspect

some of the engineering works located in the city, among the most prominent of which are James Archdale and Co., Manchester Works; Aston Manor Corporation Electric Power Station; Birmingham Corporation Electric Supply Station; James Cartland and Son; Elkington and Co.; General Electrical Co., Witton Works; Joseph Gillott and Sons, Metallic Pen Manufactory; National Telephone Co.'s Exchanges; F. and C. Osler; Taylor and Challen, Derwent Works; H. W. Ward and Co.; Webley and Scott; E. G. Wrigley and Co., Foundry Lane Works.

The older part of the city is crowded with these workshops and warehouses, but the modern part is well built and full of fine specimens of architecture. Most of its municipal undertakings date back to 1875 when Mr. Joseph Chamberlain, then its Mayor, inaugurated the new era.

A Ladies' Committee, consisting of the Lady Mayoress, Mrs. W. H. Bowater, Chairman, Mrs. Horatio Lane, Honorary Secretary, and Mesdames C. G. Beale, George Beech, Eric M. Carter, James Chatwin, George Vonaty, A. E. Cutler, David Davis, H. Ashton Hill, E. C. Keay, E. Antony Lees, Sheffield, J. D. Steven, William Tangye, J. C. Vaudrey and Miss Vaudrey, W. E. Warden, and Philip J. Worsley, on Tuesday and Wednesday mornings escorted the visiting ladies to various points of interest in the locality, providing special omnibuses for the trip.

Many of the members also accepted Mr. George Tangye's kind invitation to visit the Watt room in Heathfield Hall which, formerly the home of James Watt, has been occupied by Mr. Tangye for the past 25 years. The room is in every detail of its contents just as Watt left it, and all who appreciated the splendid genius of this early engineer could not but view with reverence the hundred-year-old stove, containing the ashes of the last fire burnt in it while Watt lived; the chest of drawers full of odd bits of metal, scraps of wood, mathematical instruments and the like; the first copying press, one of Watt's inventions, now standing with the dust of years upon it; his lathe with its lamp and tools untouched and the leather apron hung up where he left it; and many perfected or half-perfected processes or machines, all showing so clearly his instinct and passion for invention. The curator of these relics, Mr. R. H. Kirton, which Mr. Tangye long ago presented to the city of Birmingham, made the visit doubly interesting by his personal guidance and explanation. A copy of the portrait of James Watt, painted by Sir William Beechy, which hangs in the dining room at Heathfield, is here reproduced through the kindness of Mr. Tangye.

The brilliant garden fête given by the Birmingham Reception Committee on Tuesday evening in the Botanical Gardens at Edgbaston, and attended by more than 5000 guests, was remarkable for the lavishness of its hospitality as well as for the splendor of the entertainment afforded and the scenic effect produced in the grounds. On every hand strings of miniature lamps and Japanese lanterns cast a radiant glow upon the paths and the awnings of the conservatories and lawn. The Lord Mayor and Lady Mayoress, Alderman and Mrs. Bowater, Alderman Sir G. H. Kenrick, Sir Oliver J. Lodge, Mr. Henry Lea and Mr. George Tangye, received the members and friends in the Floral Hall which was especially decorated for the occasion. Music was furnished by the band of the Royal Marines of Portsmouth and during the evening a series of fine fireworks was displayed, including a set piece showing the British and American flags crossed in the air. An elaborate luncheon was served in the tents and the American guests were conveyed to and from their hotels by special motor omnibuses.

WEDNESDAY, JULY 27

The meetings in the Midland Institute were resumed on Wednesday morning at 10 o'clock, when the following cablegram was read from President Westinghouse in reply to that of Mr. Aspinall sent on Tuesday: "Express my deep appreciation to Lord Mayor, Aspinall, Goss and Members both associations for their expressions of regret because of my absence and for their good wishes. I have the highest hope that the Joint Meeting will be of permanent value in further cementing the relations between the societies, and in promoting coöperation between the engineers of the two countries."

The following papers were then presented and discussed: High-Speed Tools and Machines to Fit Them, by H. I. Brackenbury, Member I.Mech.E., Elswick Works, Sir W. G. Armstrong, Whitworth & Co., Newcastle-on-Tyne; Rapid Production in Machine Work; Abstract of Data Collected by The American Society of Mechanical Engineers, read by John Calder, Mem.Am.Soc.M.E., Manager, Remington Typewriter Works, Ilion, N. Y.; Data on Manufacturing Methods with Machine Tools, by Luther D. Burlingame, Mem.Am.Soc.M.E., Chief Draftsman, Brown & Sharpe Manufacturing Co., Providence, R. I.; and Development of High-Speed Drilling Machines, by L. P. Alford, Mem. Am. Soc. M. E., Engineering Editor American Machinist, New York. They were

iscussed by J. Hartley Wicksteed, William Lodge, Dempster Smith, rank B. Gilbreth, H. I. Brackenbury, Daniel Adamson, George ddy, Alexander Taylor, W. F. M. Goss and John A. F. Aspinall.

Papers on Tooth Gearing, by J. D. Steven, Associate Member I. lech.E., Messrs. E. G. Wrigley & Co., Soho, Birmingham; and on nterchangeable Involute Gearing, by Wilfred Lewis, Mem.Am.Soc. I.E., President Tabor Manufacturing Company, Philadelphia, and hairman of the Committee on Standards for Involute Gears, were also ead in abstract, and were discussed by P. V. Vernon, C. R. Gabriel, uther D. Burlingame, Daniel Adamson, Thomas Humpage, R. M. Veilson, J. R. Williams, and Wilfred Lewis.

President Aspinall moved that the following resolutions of thanks o their hosts and to the many people in and around Birmingham for he great hospitality which they had extended to the members of the wo organizations be accepted:

That the best thanks of the Members of The Institution of Mechanical Engineers and The American Society of Mechanical Engineers in this meeting ssembled be given:

To the Right Hon. the Lord Mayor of Birmingham, Alderman W. H. owater, for his welcome of the President, Council, and Members of the two nstitutions to the city of Birmingham; for his and the Lady Mayoress's kind nvitation to a Reception in the Council House; also for his courteously ending the Town Hall for the purposes of the luncheons.

To the Ladies' Committee for so kindly entertaining the lady visitors.

To the Chairman of the Reception Committee, the Lord Mayor; the Vice-hairmen, Alderman Sir George H. Kenrick, Mr. Henry Lea, Sir Oliver J. odge, D.Sc., Ll. D., F.R.S., Mr. George Tangye; the Hon. Treasurer, Ir. Alexander Fyshe; and the members of the Birmingham Reception Committee, for the attractive programme they have prepared for the meeting and xcursions, and for their hospitable entertainment of the members at the rden fête.

To the Chairman and Directors of the South Staffordshire Mond Gas ower and Heating Co.), the Pump and Power Co., the Austin Motor Co., e Metropolitan Amalgamated Railway Carriage and Wagon Co., Mr. F. W. acaulay, Messrs. E. G. Wrigley and Co., Messrs. Mitchells and Butlers, essrs. Walter Somers and Co., and the numerous proprietors of places of gineering interest in Birmingham, Coventry, Rugby, and neighbourhood, r their kindness in throwing open their Works for the visits of members d for hospitalities; also to the Birmingham and Midland Institute, the rmingham Association of Mechanical Engineers, and various clubs and the rmingham Exchange for the extension of hospitable facilities.

To the Right Hon. the Earl of Warwick for inviting the members and ladies visit Warwick Castle.

To the Right Hon. the Earl of Clarendon for permitting the members and ies to visit Kenilworth Castle.

To the Right Hon. Lord Leigh for permitting the members and ladies to visit Stoneleigh Abbey.

To the Mayor and Corporation of Worcester for their civic welcome; to the Very Rev. Dean of Worcester for permission to visit the Cathedral; to the Worcester Royal Porcelain Co., for permission to visit their works; and to Mr. Joseph Littlebury for his reception and address at "Ye Antient Commandery"; and to Mr. C. J. Seaman for arranging the visit to Worcester.

To the Very Rev. Dean of Lichfield for permission to visit the Cathedral; to Councillor Charles Harradine, chief verger, for conducting the members and ladies over the Cathedral; to Councillor William A. Wood, Chairman of the Johnson Birthplace Committee, for conducting them over Dr. Johnson's house; and to Alderman Herbert M. Morgan, for inviting them to the Old Grammar School house, Lichfield.

To the Council of the University of Birmingham for the reception and entertainment of the members and ladies at the new buildings.

To Mr. George Tangye for his invitation to visit the Watt room at his residence.

To Messrs. Alfred Herbert, the Daimler Motor Co., and to the Wolseley Tool and Motor Car Co., for inviting the members to visit their works, and for their kindness in entertaining the members at luncheon.

To the Honorary Local Secretaries, Mr. Fred. M. Lea and Mr. Howard Heaton, for planning numerous visits to places of interest in Birmingham and neighbourhood, and for the admirable arrangements which their forethought and energy have provided during the meeting.

To the London and North Western, the Great Western, the Midland, and other railway companies of Great Britain for special traveling facilities connected with the meeting.

The Secretaries of the two societies were instructed to transmit these resolutions to the various corporations and individuals and Professor Hutton voiced their support by the American members. The resolutions were carried by acclamation.

Wednesday Afternoon and Evening

Wednesday afternoon, after luncheon again served in the Town Hall, was also spent in sightseeing. Many availed themselves of the opportunity to visit the new buildings of the University of Birmingham, opened in July 1909 by the late King Edward, which is splendidly equipped for the study of chemistry, physics and mechanical, civil and electrical engineering. No small part of the formation of this, the leading technical college in Great Britain, was due to the genius and untiring efforts of Mr. Joseph Chamberlain, who in 1898 in a public announcement planted the seed of which this great group of buildings is now the harvest. It was at the suggestion of an

American citizen, Mr. Andrew Carnegie, by whom a donation to the fund was made, that a committee was sent to investigate the work done in America, as a result of which the American system of engineering was introduced into the University by its Council. Sir Oliver J. Lodge, a man of broad sympathies and of world-wide scientific reputation has as its Principal done much by his remarkable personality to realize Mr. Chamberlain's ideal that the University "be not only a school of general culture but practically assist the prosperity and welfare of the district by attention given to teaching science in connection with its application to local industries and manufacturies." On arrival at the University the party were received on the steps by Sir Oliver J. Lodge and in the rotunda by the Vice-Chancellor, Alderman C. G. Beale the Pro-Vice-Chancellor, Alderman F. C. Clayton; the Vice-Principal, Prof. R. S. Heath, and the Professors. The buildings and grounds were fully inspected and after tea served on invitation of the Council of the University in the Great Hall, a magnificent edifice in which all public ceremonies are held, the guests returned to Birmingham in the special motor omnibuses provided for the trip.

A trip was made by others to the brewery of Messrs. Mitchells and Butlers, at Cape Hill, Smethwick, under the guidance of the deputy Chairman, W. Walter Bulter. The malt used in the manufacture of beer is produced on the premises, and the beer when finally manufactured is run into casks by a special apparatus which ensures absolute cleanliness. A display of the company's Volunteer Fire Brigade, which has won several prizes, was given in the presence of the visitors. The directors provide for the recreation of their employees in bowling greens, cricket grounds and a football field, as well as rooms for ambulance practice, lectures, etc. Conveyances and refreshments were offered to the sightseers through the courtesy of the company.

The reception given by the Lord Mayor and Lady Mayoress in the Council House on Wednesday evening, was largely attended and much appreciation expressed of the beauty of the floral decorations and the excellence of the music. The Council House contains a large reception room and art gallery besides the Council Chambers, and all of these were thrown open to the guests. Refreshments were served in the gallery at the conclusion of the reception, and the guests conveyed to their hotels in special motor omnibuses. The Lord Mayor and Lady Mayoress, who personally attended the

various functions, not only contributed much to the occasion by their presence but very effectively emphasized the cordiality of our reception.

THURSDAY, JULY 28

Both organizations bade farewell to Birmingham on Thursday morning with many expressions of appreciation of their delightful sojourn and regret at leaving the many friends who had made them welcome. The entire day was devoted to sightseeing, all the plans, which provided for four alternative excursions, having as an objective point the arrival of the members in London that same evening, where on Friday and Saturday the final sessions of the meeting were to be held.

The guests on one of these trips visited Coventry where the Edgwick Works and Foundry and also the Head Works of Messrs. Albert Herbert were inspected under the personal guidance of Mr. Herbert himself, Member of the Institution. This firm manufactures horizontal and vertical milling machines, capstan lathes, automatic screw and turning-machines, light drilling-machines and universal grinding machines. Piece work is employed throughout, a separate price being given for each operation. On Mr. Herbert's invitation the party took lunch in the new building of the company.

Some of the party on arrival in Coventry went instead to the works of the Daimler Motor Company where they were escorted through the buildings by Percy Martin, Esq., Member of the Institution, and were interested in viewing the thirteen different trades brought into operation at these works, namely, machining, fitting, engine-testing, erecting, copper-smithing, electro-plating, etc., the whole occupying in shops alone 8½ acres of floor-space. The company had provided luncheon for the party which was served at the works.

From Coventry the party proceeded to Rugby, where one group visited the works of Messrs. Willans and Robinson, under the guidance of the general manager, James C. Peach, Esq., Member of the Institution, the principal output of these works being steam turbines, steam and oil engines, condensing plants and pumps. Others inspected the works of the British Thomson-Houston Company, with the chief engineer, H. N. Sporborg, Esq., as escort. This company manufactures electrical apparatus and Curtis turbines for traction, lighting and power purposes.

Another trip took the sightseers to Lichfield, stopping at Hammerwich en route, where under the guidance of the engineer, H. Ashton Hill, Esq., they visited the Pipe Hill Pumping Station of the South Staffordshire Water Works Company, which supplies a population of nearly three-quarters of a million. At Lichfield they were shown through the finely-proportioned three-spired cathedral one of the best existing types of the fourteenth century English church, by the chief verger, Councillor Charles Harradine. This edifice is constructed of red sandstone and the western façade, the principal entrance, has a wonderful richness of decoration. In this same town also, Dr. Samuel Johnson was born and the party were fortunate in viewing his birthplace under the guidance of the Chairman of the Johnson Birthplace Committee, Councillor William A. Wood. In the middle of St. Mary's Square, facing his father's house, is a colossal statute of the doctor himself, which looks down upon the spectator from a pedestal ten or twelve feet high. Alderman Herbert M. Morgan, ex-Mayor of Lichfield, took the visitors through the Old Grammar School, where Johnson, Addison, Elias Ashmole, Garrick and Darwin once sat upon the rude benches and no doubt spent many uncomfortable hours.

Other members of the Society visited the works of the Wolseley Tool and Motor Car Company at Adderly Park, about two miles from the center of Birmingham, which devotes exclusive attention to the manufacture of motor-cars and petrol engines for marine, aeroplane and various purposes, and is equipped with high-class machine tools.

The rest of the travelers made a trip to Kenilworth, Warwick and Stratford-upon-Avon, one group proceeding first to Kenilworth, thence to Guy's Cliff and Warwick, and concluding with a visit to Stratford; and the other going first to Stratford and from there to Warwick and Kenilworth, the two parties passing each other en route. In one case luncheon was procured at Warwick, and in the other at Stratford, in the old Red Horse Hotel which an American finds it impossible not to associate with our own Washington Irving.

At Kenilworth the party viewed the magnificent ruins of the old castle, so full of memories of the days of Elizabeth and of her courtier, the Earl of Leicester. The picturesque Guy's Cliff, which contains the cave in which Guy, first Earl of Warwick, is fabled to have passed his latter days and to have been buried, formed a fitting introduction to the gray towers of Warwick which King

Cymbeline is said to have founded at the beginning of the Christian era. The river Avon, which flows before the castle, so perfectly reflects it in its depths that Hawthorne's fancy with regard to the reality of the mirrored image and the unreality of the upper structure seems amply justified. Through the courtesy of the Earl of Warwick the castle with its many historic relics and architectural beauties was thrown open to the visitors.

At Stratford-upon-Avon, now a successful place of business and often for that reason a disappointment to the visitor because of its "newness," the party visited Shakespeare's birthplace where the beholder must always marvel at the contrast presented in the humble surroundings of the man whose splendid imaginings have so peopled our world; the church in which stands his tomb engraved with the famous "curse"; Anne Hathaway's Cottage of much the same rude order as Shakespeare's house; and the Memorial Theatre, a more modern structure. On all of these excursions as on the previous day, the amplest provision and care had been made for the conveyance and refreshment of the travelers.

More than 800 guests, even after this strenuous day, assembled in the evening at the delightful conversazione given in the rooms of the Institution. This building, which has been erected since the former visit of the American members to England in 1889, was much admired by all for the beauty of its architecture and decorations and for its fine site overlooking the waters of St. James Park. President and Mrs. Aspinall received the guests in the large hall which is decorated with Hungarian oak panellings, surmounted by red walls and enriched ceilings. During the evening, music was rendered here and in the library by the band of the Royal Artillery and by several fine vocalists. A short lecture illustrated by lantern slides was given by Dr. H. S. Hele-Shaw, on Stream Line Experiments Illustrating Aeroplane Stability. Refreshments were served in the Marble Room.

FRIDAY, JULY 29

The concluding professional session of the English Meeting was held on Friday, in the Institution House of the Civil Engineers, which is diagonally opposite the headquarters of the Mechanical Engineers. On account of the fatigue of the previous day the attendance was small, but those who were present were repaid by the opportunity

of meeting in the dignified rooms of the Institution and of participating in the discussion of especially able papers on Electric Traction. The societies were welcomed by Mr. Alexander Siemens, Senior Vice-President, who expressed the Institution's great pleasure in thus offering to the meeting the use of their theatre. President Aspinall responded and in expressing his thanks spoke of the improbability that another such gathering would be held in the historic building, because of the early occupation by the Institution of their new home. Dr. Goss, on behalf of the American members, spoke of the charm such a building had for those from a newer environment and of their appreciation of being able to gain some acquaintance with the Institution.

The following papers were then read in abstract: Electrification of Suburban Railways, by F. W. Carter, of Rugby; The Cost of Electrically-Propelled Suburban Trains, by H. M. Hobart, of London; Economics of Railway Electrification, William Bancroft Potter, Mem.Am.Soc.M.E., Engineer, Railway and Traction Department, General Electric Company, Schenectady, N. Y., presented by H. H. Barnes, Jr., of New York; The Electrification of Trunk Lines, by L. R. Pomeroy, Mem.Am.Soc.M.E., J. G. White, Co., Inc., New York, N. Y.; The Electrification of Railways, by George Westinghouse, President Am.Soc.M.E., Pittsburg, Pa., presented by Charles F. Scott, of Pittsburg. These were discussed by Charles F. Scott, H. F. Parshall, J. Dalziel, Sidney Stone, Edgar Worthington, H. M. Hobart, Angus Sinclair, J. G. Wilson, F. R. Hutton, F. W. Carter, H. H. Barnes, Cary T. Hutchinson, and J. R. Williams.

The following resolutions of thanks were then put to vote and carried by acclamation:

To Dr. and Mrs. Maw and Sir John and Lady Thornycroft for their kind invitations to the members and ladies to attend garden parties.

To The Times for the invitation to visit their printing works.

To the Council of the Institution of Civil Engineers for so kindly placing their lecture hall at the disposal of the members for the purposes of the London meeting.

To His Worship the Mayor of Windsor, Councillor C. F. Dyson, for courteously lending the Guildhall for the purposes of the luncheon in Windsor; also to His Worship and Mr. George Mitchell, Mr. Christopher Sainty and Mr. George Willis for conducting the members and ladies at Windsor.

That the Secretaries of The Institution of Mechanical Engineers and The American Society of Mechanical Engineers be severally instructed to transmit the above resolutions to the various corporations and individuals who have

done so much to make the Joint Meeting enjoyable and memorable on both sides of the Atlantic.

Prof. F. R. Hutton made the concluding remarks of the session, speaking at some length of the enjoyment of the American members of the Birmingham and London meetings, and offering the following additional resolutions:

The American Society of Mechanical Engineers, present by invitation at the closing session of the Joint Summer Meeting of 1910 with The Institution of Mechanical Engineers, asks permission to offer for record the following minute, and requests its Acting President to put the resolution to vote:

The American Society of Mechanical Engineers has been enveloped in an atmosphere of courteous, friendly, and devoted attention from the moment that the vessel which carried the official and organized party entered the River Mersey at Liverpool. Beginning with a reception on the steamer, at which the President and Secretary of the Institution officially welcomed the party, in conjunction with representatives of the city and other interests of that progressive corporation, and continuing through the arrangements for comfortable and convenient transportation by train to the place of first meeting; providing on arrival for prompt and satisfactory hotel accommodation, and for organizing, in a masterly way, which extended even to the most minute details for the enjoyment of the visitors on excursions, in affording opportunities to visit works, for transportation, and for motor drives in the historic Midlands of England, The Institution of Mechanical Engineers has placed The American Society of Mechanical Engineers under an obligation which no mere words or resolutions are an adequate medium to discharge. The visitors can only assure the home Society, its President, its Council, its Secretary and its organizing committee that just because they are themselves organizers and doers they are able most thoroughly to appreciate such work well done.

The American Society also appreciates most sincerely the generous purpose which has spared no sacrifice when the desired object of the hosts has had to be met by the ordinary commercial procedure as respects outside parties. Hence the Society moves and seconds the following resolutions:

Resolved, that The American Society of Mechanical Engineers desires, in addition to the resolutions passed in Birmingham thanking those who had put both bodies under a pleasant debt of obligation, to put on record the following special resolutions of thanks:

Resolved, that The American Society thanks The Institution of Mechanical Engineers, its President, Council, Secretary and Committee for their ceaseless, unremitting, and painstaking effort for the pleasure and success of the Joint Meeting of 1910 in Birmingham and London.

Resolved, that this Joint Meeting will be a memory of delight and pleasure for all the Americans who have been privileged to share in it.

Resolved, that The American Society of Mechanical Engineers desires to thank the Birmingham Reception Committee for certain special considerations at their hands, which were extended exclusively to the American members of the Joint Party, and requests the Institution to be the channel for conveying such action of thanks.

Resolved, that The American Society of Mechanical Engineers desires by this action to express for the ladies, who have accompanied the members, something of the appreciation of both members and ladies for the delicate and considerate attention which has made their participation a delight and a possibility. The members feel that international friendships springing from these days of close and enjoyable association are sure to last forward into future happy years.

Resolved, that The American Society of Mechanical Engineers requests The Institution of Mechanical Engineers to incorporate this minute and action as part of its record of the Proceedings of the Joint Summer Meeting of 1910.

These were carried by the rising vote of all the Americans present.

Friday Afternoon and Evening

Two very enjoyable garden parties were given on Friday afternoon, one at the home of Dr. William H. Maw, Esq., Past-President of the Institution, and Mrs. Maw, at Addison Road, Kensington, and the other at Eyot Villa, in Chiswick Mall, the home of Sir John Thornycroft, Member of the Council, and Lady Thornycroft, at both of which the visitors were given a delightful glimpse of English home life.

A number of members also inspected the British Museum, and the Times Office in Printing House Square through which they were conducted by the Chief Engineer, J. P. Bland, Esq., Member I.Mech.E. These offices stand on the site of the building from which the paper was first issued in 1785.

An event to which the American members had looked forward with much delightful anticipation was the banquet given by the Institution on Friday evening in the Connaught Rooms, the largest dining hall in the city of London. After the usual toasts to the Crown had been given, President Aspinall proposed The President of the United States, which was acknowledged by the American Ambassador, the Hon. Whitelaw Reid. Mr. Reid said that he regarded this toast not only as a tribute of high regard for the personal character of the present occupant of the Presidential chair, but also a token of profound respect for the whole country over which he ruled, and that he believed the material conquests which had created and developed the great empire of America, occupying more than one-quarter of the habitable surface of the globe and comprising nearly one-third of its inhabitants, were due to no class more largely than to the mechanical engineers of the two countries represented at this gathering.

Sir William H. White in giving the toast, The American Society of Mechanical Engineers, recalled the fact that it was founded but 30 years ago and yet had now a membership of about 4000. He referred particularly to the long years of service for the Society of Prof. F. R. Hutton, who, he said, had together with the present Secretary, promoted the Society's growth and success, and that by virtue of their ideals for its welfare the American organization was safe in their hands. Professor Hutton in responding said that the present gathering was the culmination of a series of meetings of mechanical engineers on both sides of the Atlantic, and that the profession which they represented underlay the civilization of the Anglo-Saxon race. The American was much at home in the United Kingdom because he and his host had a common ideal.

A toast to Our English Guests, proposed by Edward B. Ellington, Vice-President of the Institution, was acknowledged by Dr. R. T. Glazebrook, Director of the National Physical Laboratory; and the final toast of the evening, The Institution of Mechanical Engineers, given by Dr. W. F. M. Goss, was answered by President Aspinall.

Among the guests of the evening were James M. Dodge, Oberlin Smith, A. H. D. R. Steel-Maitland, M. P., Dr. Worcester, Mr. and Mrs. J. Hartley Wicksteed, Mr. and Mrs. F. W. Taylor, Dr. and Mrs. Wm. Maw, Charles Hawksley, the Lord Mayor and Lady Mayoress of Windsor, E. P. Martin, Mr. and Mrs. Ambrose Swasey, Charles Kirchhoff, J. L. Griffiths, United States Vice-Consul, Mr. and Mrs. John R. Freeman, Sir Gerard and Lady Muntz, Henry Lea, C. F. Scott, Mr. and Mrs. Jesse M. Smith, Mr. and Mrs. James Hartness, Mr. and Mrs. Wm. H. Wiley, Calvin W. Rice, Mr. and Mrs. Willis E. Hall, Mr. and Mrs. Henry L. Gantt and Dr. Hele-Shaw. Music was furnished during the evening by the Imperial Orchestra.

SATURDAY, JULY 30

All-day excursions to Windsor and Marlow occupied Saturday, half of the party leaving London by special train for Windsor and proceeding by the special steam launches, Empress of India and Majestic, to Marlow, and the other half going by train to Marlow and thence to Windsor by the launches, His Majesty and Princess Beatrice, the two groups passing each other on the river. A view of the two parties is given herewith. In one case luncheon was served in Windsor at the Guildhall, with tea at the Compleat Angler and George and Dragon Hotels in Marlow, a picturesque fishing resort;

while in the other the party had luncheon on the launches and tea in the Guildhall. The trips on the launches were most enjoyable and gave a complete idea of life on the Thames, including the famous Henley regatta, then in progress. At Windsor, the Lord Mayor, Councillor C. F. Dyson, Alderman George Mitchell, Mem. .Mech.E., Christopher Sainty, Mem.I.Mech.E., and George Willis, Assoc. Mem.I.Mech.E., personally conducted the party about this favorite residence of the English monarchs.

On Saturday evening Sir William H. White, Past-President of the Institution and an Honorary Member of the Society, together with Lady White entertained the Councils of the Institution and the Society at dinner in the Garden Club, which overlooks the grounds of the Japan-British Exposition at Shepherd's Bush. The picturesque Japanese Gardens, with their flavor of old-world romance, and the fine exhibits of ancient and feudal Japan, contrast strongly with the wonderful modern enterprise of both nations, and make the spot vastly interesting. Many Americans took advantage of the opportunity to see this Exhibition, assembling later in the room which had been especially set aside for the purpose by those in charge.

SUNDAY, JULY 31

Interest has long been manifested by the Society in the Sir Benjamin Baker Memorial Window in Westminster Abbey, which was unveiled on December 3, 1909, and it was a pleasure to have an opportunity on Sunday evening of viewing it. The window, which is situated on the north side of the nave, contains two lights having the figures of King Edward III and Abbot Simon Langham, under canopies, both lights being framed with borders containing niches which hold twelve statuettes and as many shields. Below these is the inscription on tablets held by the figures of angels: IN MEMORY OF SIR BENJAMIN BAKER, CIVIL ENGINEER, FORTH BRIDGE, ASSUAN DAM. B. 1840. D. 1907. The members assembled in the Dean's Yard and were conducted through the Abbey with its many famous spots by the Sub-Dean, the Very Reverend Dr. Duckworth. At the vesper service in the nave, at seven o'clock, seats had been assigned to the representatives of the two societies and in his sermon the Bishop of Lewes gave a special greeting to the American visitors, of which 250 were present.

Taking his text from I Cor. xii. 5, "There are differences of administration, but the same Lord," the Bishop declared this to be the

exact opposite of the theory that everybody ought to be alike. Each had his special place and value, which were appraised differently by men but not by God. There were also differences of method, and not all seemed successful. Here amidst the memorials of the mighty dead we were never allowed to forget for one moment the vast range of God's workings in the life of men. Men great in war and great in peace, men far from perfect, each humanly weak, were here, but here because of the power of ministration that was in them. Differing widely in gift, method, opportunity, they were united in being searchers after the truth, interpreter's of God's plans and purposes for man, men who tried to serve their generation by the will of God. Sir Benjamin Baker was such a worker in the field of engineering service. The builder of Forth Bridge hardly needed any further remembrance, but as a man of noble character, as well as a scientific genius, he belonged among those who shared his talents and his strenuous life to interpret God's plans to men.

This service was regarded as the benediction of the meeting in England, which could not have been more appropriately ended.

On Monday evening, on the eve of departure on their second world tour, Ambrose Swasey, to whose forethought, wonderful tact and administrative ability it is not too much to say that a great part of the success of the Society's trip to England is due, together with Mrs. Swasey gave a dinner to the members of the Council of the American Society in the Hotel Russell, London. Leave takings were general on every side, some of the party going on to the Continent and others returning at once to America.

Among the kindly messages received during the English Meeting was the following telegram from the Junior Institution: "President Sir Henry Oram and Council Junior Institution Engineers desire join expressions welcome American Society Mechanical Engineers on visit Great Britain." Every member also received from the President of the Institution of Mechanical Engineers a very handsome brochure, containing portraits of the Presidents of the two organizations represented at the meeting, and brief biographical sketches of George Stephenson, Matthew Boulton, James Watt, Richard Trevithick, Robert Fulton, and William Symington, profusely illustrated with portraits and with quaint designs reproduced from Stuart's Anecdotes of Steam Engines, published in 1829.

Such an account as is here presented can give but a glimpse of the visit to England, remarkable for its comfort and sociability and for the vast entertainment provided by the English Society, presenting

as it did a happy combination of the technical and social features which were all blended together in the increased mutual regard, as removed from rivalry, of these two great national organizations. As no American can find himself a stranger in this land of his forefathers and his traditions, so no member of a professional organization on this side of the water can come in contact with those of a similar vocation in England without experiencing a sense of common ideals and common aims. Of the wonderful hospitality accorded by the English Institution too much cannot be said; nor can thanks ever express to the British members the gratitude and pleasure of their American guests. Not the slightest detail seems to have been omitted, the machinery of the entire gathering moving so perfectly as to be practically invisible. The finely prepared program, with its maps covering every inch of the ground to be traveled during the meeting, was an illustration of this wonderful attention to detail, including information, in addition to fullest data of meetings and trips, which met every possible want of the traveler, from restaurant locations and cab fares to the dates of departure of steamships carrying mails. The many welcoming hands held out on every side made the meeting a homecoming rather than a visit, to be looked back upon by all as a red-letter season in the life of the Society. The greeting of the English engineers when they shall next come to American shores, in a way worthy of their own welcome, is already joyfully anticipated by our members.

?OSIUM ON LOCOMOTIVE HAND-LING AT TERMINALS

No. 1290*a*

:NGLISH RUNNING-SHED PRACTICE

By Cecil W. Paget, Derby, England

M. I. Mech. E.

The Running-Shed Buildings

running-sheds in England are of two types:

1 Those in which the roads are laid parallel, usually called straight sheds.

2 Those in which the roads radiate from a center turntable, called round sheds.

The straight sheds are economical in first cost and maintenance, ess they are of the type known as "through sheds" they are d to work; the latter class are necessarily drafty.

The center turntable type, though more expensive to build, s considerable advantages of working because engines can be ɔt in and out without moving others. The radial arrangement pits also lends itself better to lighting and convenience of about. There is plenty of room towards the end of the pits rs to work at the bench between two engines, and the work of ; out boilers, swilling out pits, and general cleaning can be thout inconvenience. To set against these advantages, there bjection that when the turntable requires lifting for repairs rs the whole of the pits served by it out of use whilst the are going on.

Plans are shown of two of the most recent sheds built in this :

ted at the meeting of The American Society of Mechanical rs with The Institution of Mechanical Engineers, Birmingham, July 1910.

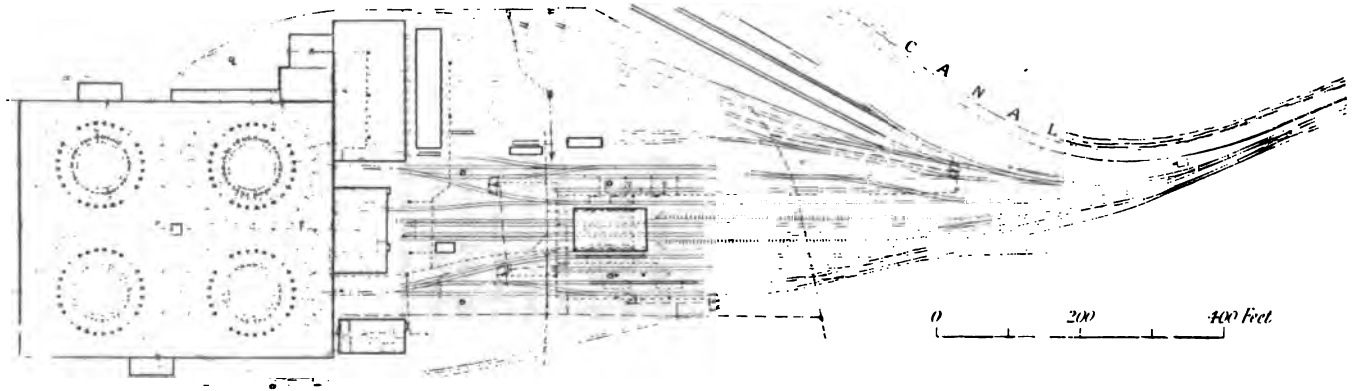


FIG. 1 TURNTABLE ENGINE SHED AND YARD, G. W. RAILWAY, OLD OAK COMMON (FIGS. 3 AND 4)

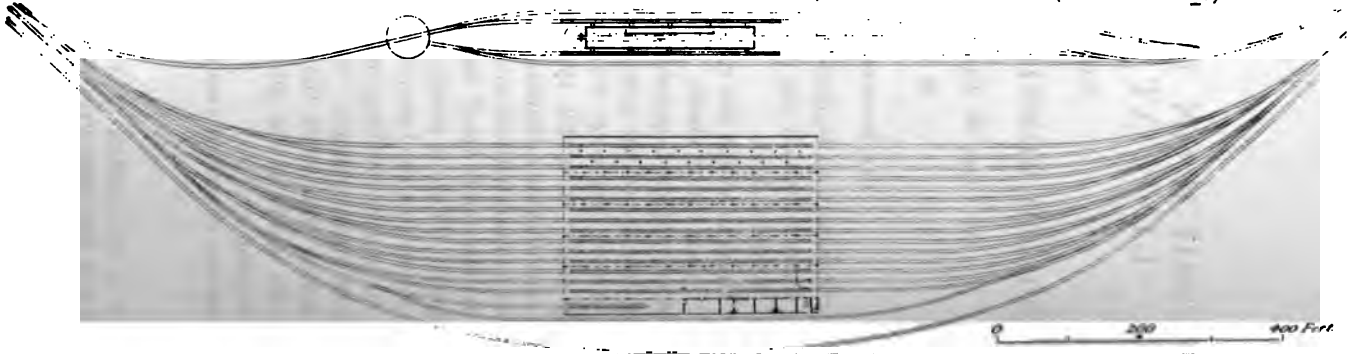


FIG. 2 THROUGH STRAIGHT TYPE ENGINE SHED AND COAL STAGE, L. & S. W. RAILWAY, EASTLEIGH (FIGS. 5 AND 6)

a Figs. 1 and 3. The Great Western Sheds at Old Oak Common, center turntable type. (Similar type shown in Fig. 4.)

b Figs. 2 and 5. The London & South Western Shed at Eastleigh, through straight type.

The necessary offices, stores, mess-rooms and lavatories should veniently placed, and reference to the plans will show their ement in the two sheds referred to, which may be taken as es of the latest British practice. Illustrations are also given pical mess room and lavatory, Figs. 7 and 8. The lavatory ted is equipped with shower baths and a separate locker ed for every man employed at the shed. The cleaners, and larly the enginemen, appreciate and regularly use the lava- nd shower baths.

Sheer-Legs and Fitters' Appliances. Attached to every shed of e are sheer-legs capable of lifting one end of an engine so that eels and axle-boxes may be removed for examination or repairs. legs were made almost universally at one time of wood, and tripod type, the single leg on one side of the rails being of strength and carrying the lifting gear. The disadvantage type, of which many are still in existence, is, that now that so engines have extended cabs, the legs have to be of great height r to allow of the trailing wheels being taken out, as the cab top t room to rise between the frame of the legs. This difficulty metimes overcome by forming the top of the legs of bow- iron castings, whilst two wooden struts were placed on either The most modern construction is, however, to use a framework l joists, the top cross-girders and gussets leaving sufficient om for any contingency. An example of legs of this type is in Fig. 9. To some modern examples is attached a small jib- which is of use in taking off the bogie-frame for examination, ; wheels, etc. A capacity of 15 tons used to be looked upon ly sufficient, but the large increase in the weight of engines nt years has led to stronger legs being required, and the more n ones are capable of raising 35 to 40 tons. The load is usually y hand by means of a crab or train of wheels operating a chain rope, which works round a sheaf or set of blocks. In some where hydraulic power is available it is employed, but the nodern method, where current can be obtained, is to use an motor.

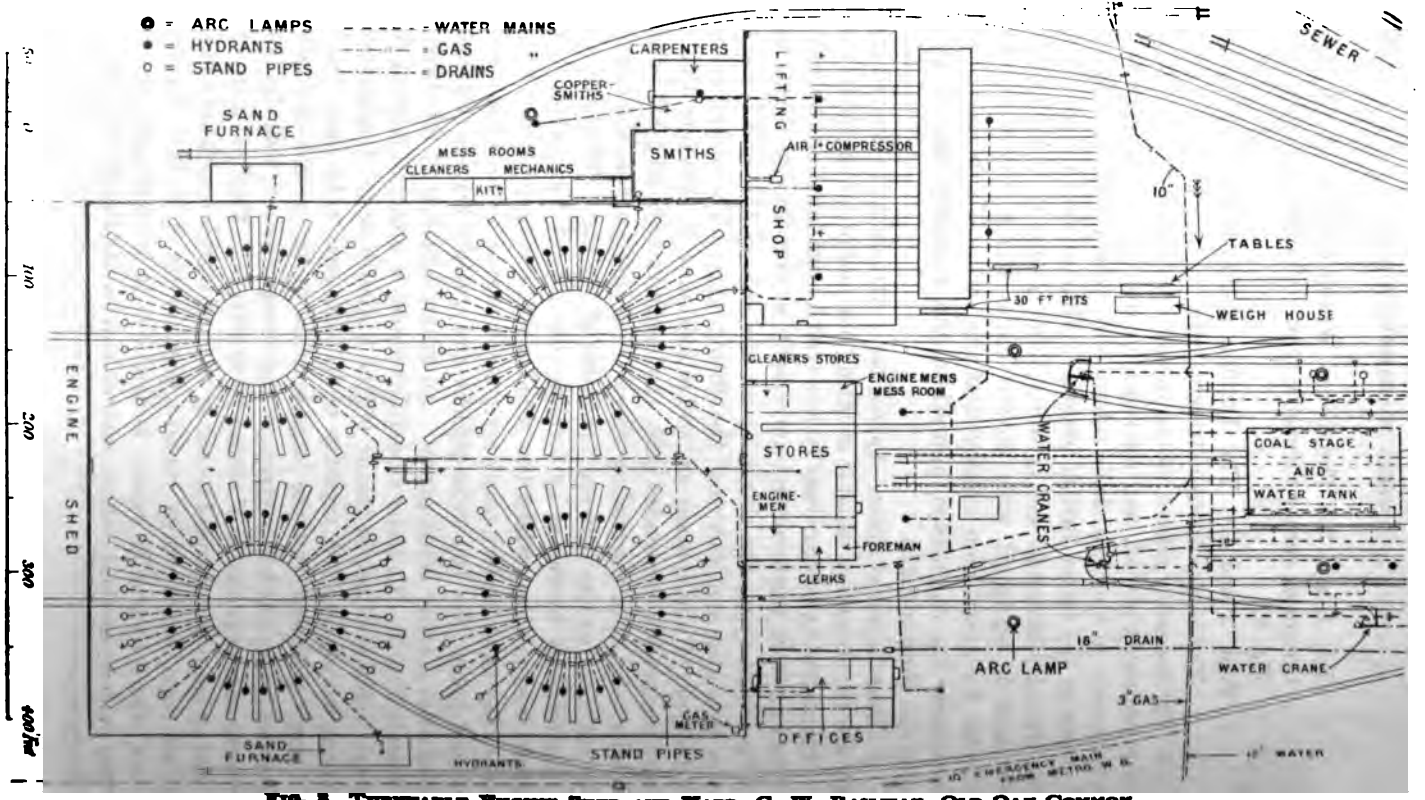


FIG. 3 TURNTABLE ENGINE SHED AND YARD, G. W. RAILWAY, OLD OAK COMMON

The position of the sheer-legs relative to the shed depends
ly upon local circumstances, but in sheds where the pits radiate
the table and the building is a square one, a set of legs is usu-
fixed on one of the longer roads, that is, one of the roads lead-
to the corners of the shed, as better work and more care are
able where men can work without being exposed to the weather.
ll cases, whether outside or indoor, the legs are placed over a pit
h is usually 2 ft. 10 in. deep below rail level.

Very little tackle of a special nature is required by shed fitters,
amongst those things which must be always at hand are jacks,
aulic and bottle, for lifting engines to change bearing springs,
lever and stands, to allow of axle boxes being tried up the horn
es, wood blocks to act as temporary axle boxes, clamps to draw
ne and tender together to facilitate uncoupling, iron lorries to
under engine when the bogie has been removed, wood blocks to
engine on, etc., as well as a good supply of ordinary shop tools.
ot attached to the sheer-legs a small crane is useful to lift a bogie-
ie off the axles when required, whilst a pair of 2-cwt. pulley blocks
often employed to allow of the boxes being tried on the axles.

Where engine and tender springs stand above the platform of
framing, a claw-spanner about 8 ft. long with one jaw much longer
the other is often employed to allow of changing the springs
out lifting.

Fitters' Stores. The stock of materials and fittings necessary to
ir or keep an engine in service should be kept down as low as
ible consistent with efficiency. The card system with a maximum
minimum for each article is quite commonly in use, and enables
eck to be kept on stock in hand and the time in which deliveries
effected. The amount of the stock depends largely upon an
ient system of supply. It is very easy to have large sums of
ey lying idle, unless a very close watch is kept upon this section.

The Lancashire & Yorkshire Railway Company distribute
es to the sheds on their system by vans, of which three are sent
daily. The vans are designed for dealing conveniently with
es, and are fitted with swing-jibs and pulley-blocks for handling
heavier articles. The system works very satisfactorily and a
ck delivery is ensured, material ordered over night being delivered
next morning at 8.30. The vans are worked on passenger trains
have resulted in freeing the passenger-station platforms, whilst
expense of delivering stores has been materially reduced.

Fig. 4. Turntable Engine Shed, Shown in Gas Lights (12-in. of Water Pressure)

12 *Lighting of Locomotive Sheds.* As the greater part of the clean-
ıg of locomotives has to be performed during the night, the question
f the lighting of locomotive sheds has received considerable attention
n many railways. In the majority of cases where gas is available
; is employed, as electric light until the recent development with
ıetallic filament lamps, has only been economical where arc lamps
re used, and such large units of light are not required. In properly
ghted sheds incandescent gas is usually employed, and this allows
f adequate illumination at reasonable cost at the points required.
Wo considerations chiefly govern the successful lighting of a shed,
hese being that the boilers of the engines should be well lighted,
nd also that sufficient illumination should be shown on the motion
ork, the latter object being the more difficult problem.

13 With straight sheds the position of the lights is naturally
estricted, the lamps having to be placed in rows between the engines,
nd if they contain two mantles, each consuming 3 cu. ft. of gas per
r., and are spaced 35 ft. apart and 11 ft. high, the result will be
ıtisfactory, although as the length of the engines stabled will differ,
he best light is not always at the point required.

14 With round (turntable) sheds a different arrangement is
equired, as the table has to be lighted separately, usually by four
ımps placed so that they will not be affected by the exhaust of
ıe engines running on and off the pits. The lighting of the sides
nd motions of the engines is a simpler matter than with straight
ieds, as the smoke-box end of the locomotive always faces the table,
ıd the motion is always about the same distance from the center.
ımps can alternately be placed so as to throw their light in the
otion on one side, and opposite the cab on the other, as shown in
g. 10. Long roads which hold two engines, it will be seen, require
o lamps. In some cases the employment of high-pressure gas
0 in. of water) is found to be advantageous, as a light of about
0 candles is obtained with a consumption of 20 cu. ft. of gas.
ıe result of this type of lighting is particularly good, as will be
n from a photograph of a shed lighted in this way, Fig. 4. In
ıny cases fittings are provided in the shed pits to afford a movable
ht, or allow of flexible connections being used for a portable light.

15 *Arrangements for Washing Out.* Washing out is usually done
ide the shed with cold water, and mains with a good head of water
laid having hydrants at convenient places. Washing out with
water, though very desirable, is not at present in general use, but
iew of the importance of the matter, it has been thought that a

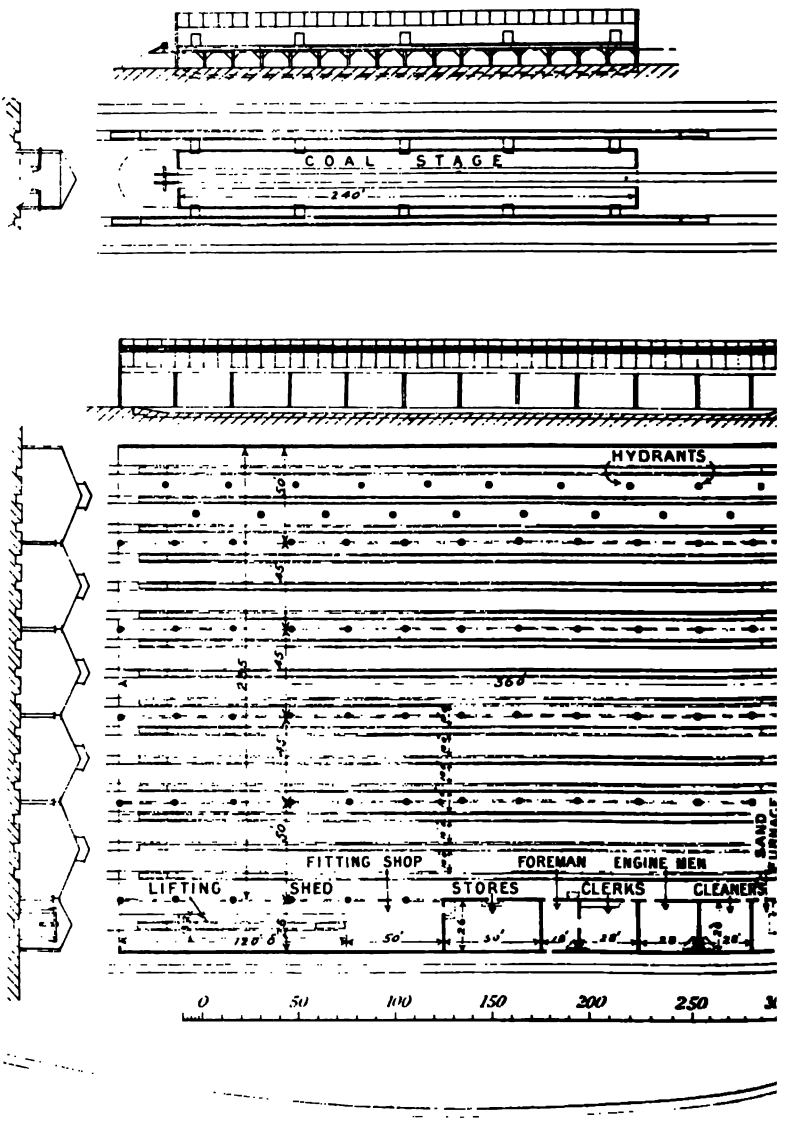


FIG. 5 THROUGH-STRAIGHT TYPE ENGINE SHED AND COAL STAGE, L. & W RAILWAY, EASTLEIGH

description of the apparatus erected by the North Eastern Railway at Gateshead would prove interesting.

16 An engine is brought in with about 60 lb. of steam still in the boiler, and by means of a flexible metallic hose-pipe a connection is made between the blow-off cock on the engine and the blow-off line of piping to the tanks which contain the hot water for washing out and filling. The engine is then blown off, and the water and steam pass away to a separator on the top of the tank containing the washing-out water. The water falls down through a coke filter-bed (which arrests any scale) into the tank, and the steam passes away through a pipe to a chamber on the top of the tank which contains the filling water, where it meets pure cold water from the main water supply. This water is heated up by the steam and falls into the tank.

17 When the engine has been fully blown off, which occupies from 10 to 20 min., according to the size of the boiler, the blow-off hose is disconnected and an armored hose wash-out pipe is connected to another line of piping through which the water from the wash-out tank is pumped, and the engine is washed out in the usual manner. A duplex Worthington pump, capable of delivering 450 gal. per min., is used for pumping the wash-out water, and this is automatically controlled so as to give a pressure of 60 lb. per sq. in. By means of the thermostatic valve the temperature of the wash-out water is maintained at 140 deg. fahr., which is as high a temperature as can be conveniently handled by the men.

18 When the washing out has been completed, and all the plugs and and mud-hole doors have been put back, the hose is shifted on to another line of piping and the boiler filled up from the filling tank with water at not less than 180 deg. fahr. This is pumped from the filling-tank by a duplex pump similar to the one mentioned above. A thermostatic valve automatically opens a valve to supply live steam for heating purposes to the filling tank when the temperature of the water in it falls below 180 deg. fahr., and shuts off the supply of steam on reaching that temperature. The waste steam from the engines that are blown off is, however, usually sufficient to give the required heat to the water in the filling tank, and it is rarely that it is necessary to use live steam for this purpose. The filling and wash-out tanks hold 6000 gallons of water each, and several engines can be blown off, washed out, or filled up, at the same time. Figs. 11 to 13 are diagrams of the arrangements of this system. With the hot-water washing and filling system, an engine can be blown off, washed out,

Fig. 6. Through-Stra[illegible]

filled up, and in steam about two hours from commencement of the operation without the boiler plates, etc., having been subjected to detrimental changes of temperature.

19 *Methods of Coaling.* The general method is to push the coal in wagons up an inclined road to a stage where it is unloaded into small tubs on wheels. The stage is of such a height that when the tubs are run out on to a small tipping stage projecting from the main stage they are over the tender, which is alongside, to be coaled. The small stages are hinged and weighted so that their normal position is

FIG. 7 MESS ROOM

ear of the loading gage. In some cases power-cranes are used, ut the method described above is the most general.

20 The South Eastern Railway Company use a power-driven levator, Fig. 14. The elevator consists of 20 buckets, each holding bout ½ cwt. of coal when loosely filled. The buckets travel on an ndless pitch chain which runs over two toothed wheels, one wheel eing at the upper end of the frame under the roof of the stage, and he other at the lower end in a pit some 7 feet below the floor of the oal stage, into which pit the coal is shoveled direct from the coal

wagons on the inside road. An electric motor, placed on a bracket fixed to the roof of the coal stage and wall of engine-shed, making about 550 r.p.m., drives by belting a countershaft on the top of the elevator frame; a pinion on this shaft gears into a spur wheel, which drives the top chain-wheel, the speed of the chain-wheels being about 25 r.p.m. Working at this speed, the buckets deliver coal down a wooden shoot on to the tenders at the rate of about one ton per minute. The coal is delivered close to the top of the tender. Gear is provided for lifting the shoot clear of the loading gage. To avoid jamming

FIG. 8 LAVATORY

the buckets in the pit with an accumulation of coal, and preventing the motor starting, an automatic switch has been devised by which the action of raising the handle of the slide admitting coal into the pit, starts the motor before the slide is actually moved, a water spray to lay the dust being turned on at the same time.

21 *Sand Furnaces.* Sand furnaces are provided in connection with every running shed, because it is important that the sand used should be dry; quite equal to this in importance is the necessity for

its being thoroughly sieved, so that no lumps can be present which might render the steam sanders ineffective.

22 *Ash-Pits.* Ash-pits are provided in suitable positions so that engines may be placed over them on their way back to the shed. The fire is raked into the pit and quenched. The ashes and clinker are afterwards thrown out and the pit kept clean, so that the drivers can move about in it freely to examine their engines. A path about 3 ft. wide is kept swept at each side of the pit for the same purpose. The ashes are thrown on to plates beyond these paths and loaded up by the engineer's ballast gangs daily.

23 *Water Softening.* Few English railways have adopted water softening extensively, though several use it on a limited scale. The softeners in use may be divided into two groups, namely, continuous-flow softeners, represented by the Desrumaux, Kennicott, Pulsometer, Reisert, Porter-Clark, and other types; and intermittent-type softeners, represented by the original Clark process and the Archbutt-Deeley[1] plant. In all softeners the chemical treatment is the same. The water is treated with a caustic alkali, usually milk of lime or lime-water, which, by combining with the free and half-combined carbonic acid and decomposing magnesium salts, precipitates the calcium carbonate and magnesia, and by the further addition of soda-ash the remaining calcium salts are decomposed and the removal of the scale-forming matter is completed. In the continuous-flow plants the chemicals are added to the water during its flow through the softener, and the precipitate is either collected on sloping plates arranged so as to divide the water into a series of shallow layers in which settlement takes place rapidly, or a filter press may be used as in Porter's arrangement. These plants occupy the least ground space, and the water loses very little head; they are best suited for waters which do not vary much in composition, such as those derived from deep wells or springs. In the intermittent-type plants the chemical treatment takes place in tanks in which a large volume of water is thoroughly mixed with the chemicals and allowed to remain quiescent until the precipitate has settled out and clear water can be drawn off, a continuous supply being obtained by using two or more tanks. In Clark's process very large tanks were needed owing to the slow rate of settling; but in the Archbutt-Deeley system the rate of settling is accelerated by stirring up the old precipitate, and much smaller tanks are needed; this type of softener is specially adapted for the treatment of waters which are variable in composition.

[1]Proc. 1898, Pt. 3, pp. 404–454.

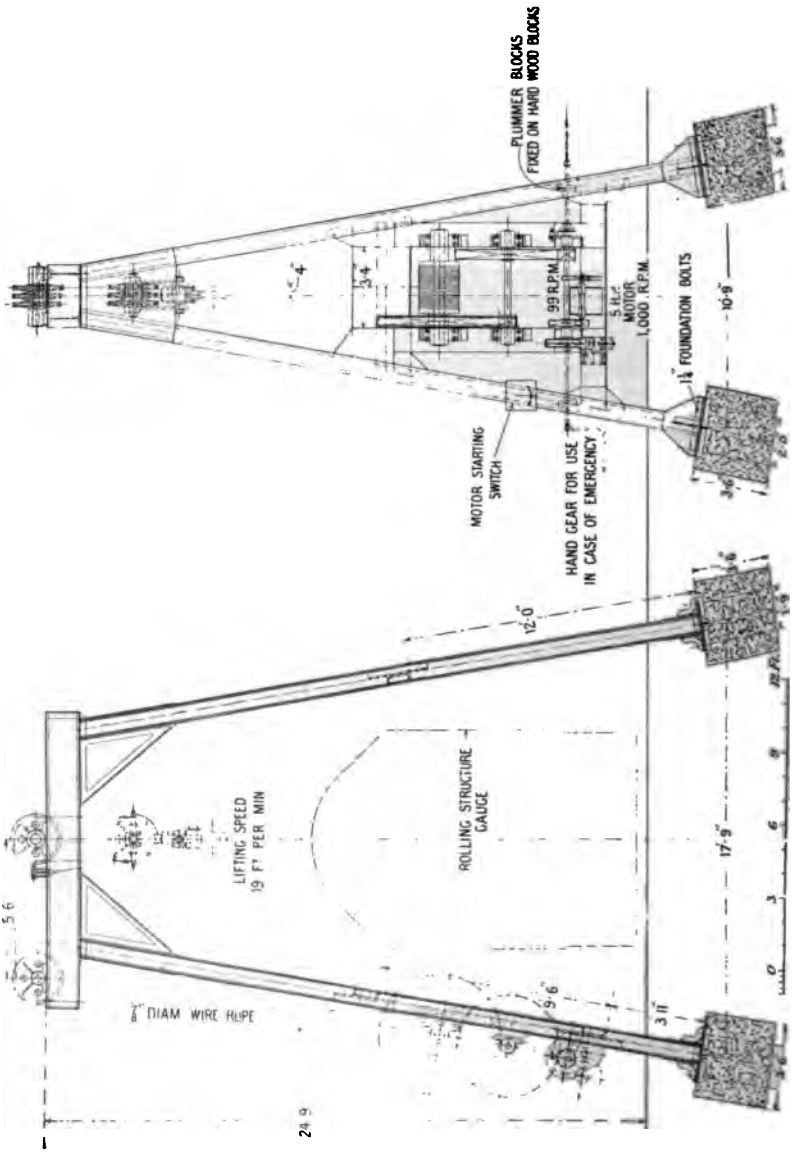


FIG. 9. LOCOMOTIVE SHEDS LEGS FOR 30 TONS. MOTOR DRIVEN

24 There are certain inconveniences connected with the use of oftened waters, as if the soluble salts reach from 150 to 300 gr. er gal. priming will take place. This will more readily occur hen sodium salts are present, owing to the use of soda-ash to decom- ose the sulphates and chlorides. If, owing to the impurities, : is necessary to soften the water with soda-ash, arrangements must

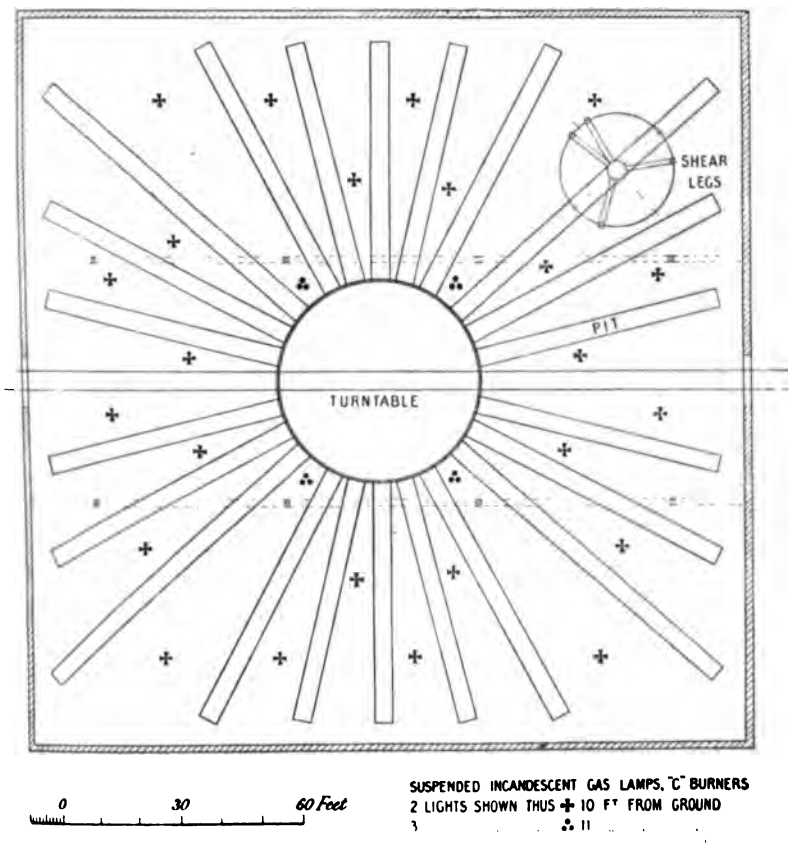


FIG. 10 GAS LIGHTING OF ENGINE SHEDS

be made to prevent trouble arising owing to concentration of salts in the boiler. This may be done either by changing the water, or by the use of blow-off or scum cocks, but neither method is at present extensively used in England. This is probably largely due to the fact that taken as a whole the waters used for locomotive purposes in this country are of fairly good quality. Owing to the

comparative smallness of the boilers, engines are, however, liable to work with steam in which there is an excess of water, and the avoidable coal consumption due to this cause may be high, although water may not be present in the steam to such an extent as to constitute priming. Experience shows that where softening has been resorted to with a bad water, considerable saving is effected in the cost of boiler repairs and renewals.

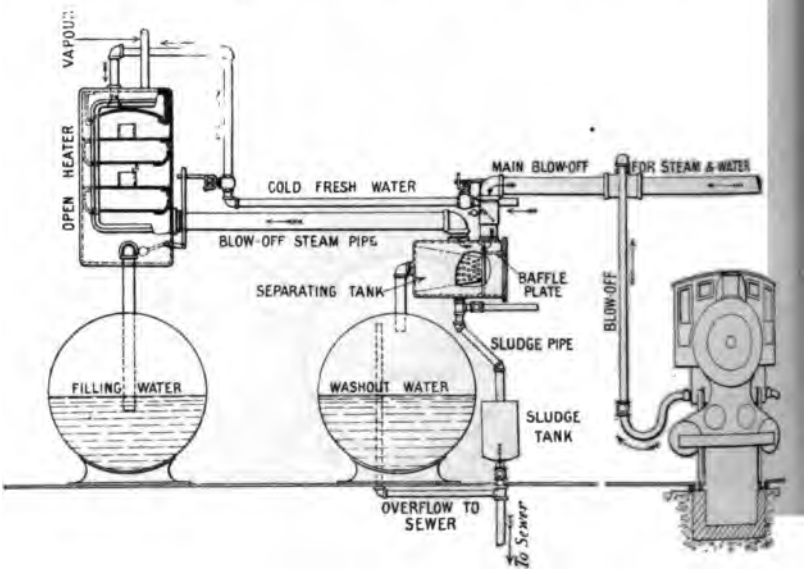


FIG. 11 ECONOMICAL SYSTEM FOR BOILER WASHING: BLOW-OFF PIPING

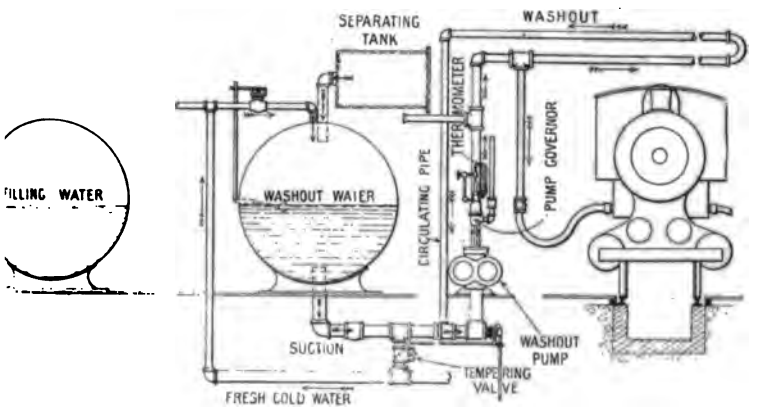
RUNNING-SHED ARRANGEMENTS

25 In order that the earning capacity of the locomotive stock may be as high as possible, it is the aim of the management to get as much work out of the engines as is consistent with safety. To do this, they must be kept in an efficient state, because apart from considerations of safety, which hold the first place, failures on the road are very expensive.

26 *Examinations.* The period between the examinations of the various parts of engines is fixed either on a time or mileage basis. On the Midland Railway the method employed depends upon the parts to be examined, fire-boxes and boiler fittings being examined on a time basis, and working parts on a mileage basis. In Appendix No. 1 are shown the margin times and mileages allowed before the

ous examinations are made. It will be noticed in the periods, the mileages, there is a fair working margin between the time an engine enters the period or mileage at which it is due for nination and the time or mileage at which it must be examined. margin is given to enable all examinations to be done together ar as possible, and prevent an engine being put out of service ral times for different examinations.

In order to enable the examinations to be regularly carried out n engines, owing to the demands of the traffic, are working for length of time away from the owning station, each engine carries ne cab a card upon which are recorded the dates of the last examions and wash-out, and if the inspection of this card shows an nination or wash-out to be due, the work is carried out and entry le on the card to that effect.



ig. 12 Economical System for Boiler Washing: Washout Piping

8 In addition to the prescribed periodical examinations, each ver when giving up his engine examines it and reports any repairs t are required. It is the practice in a good many sheds also to ploy examining fitters for the purpose of examining engines when y are put in the shed after work.

9 *Running Repairs.* As a result of the examination and reports the drivers and examining fitters, the necessary small repairs and ustments are done by the running-shed fitting staff. On the dland Railway the books into which drivers and fitters used to er their reports have been replaced by cards which, on being ered up, are dropped into a locked box. In the case of no repairs ng required a "nil" card is put in. By this method the foreman

fitter is able to arrange his work better. He has before him in a convenient form the amount of repairs of various kinds that require doing, and by associating this information with the train-board he can tell by what time the work must be done and is able to arrange his men accordingly.

30 *Washing Out.* Owing to the use of different qualities of water, the periodic washing out of boilers varies considerably. The general practice is to wash out passenger engines after 500 miles work, and freight engines after 800 to 900 miles work. At busy times there is no doubt that the time allowed for engines to cool is frequently not as long as it should be, and, with the object of avoiding the damage

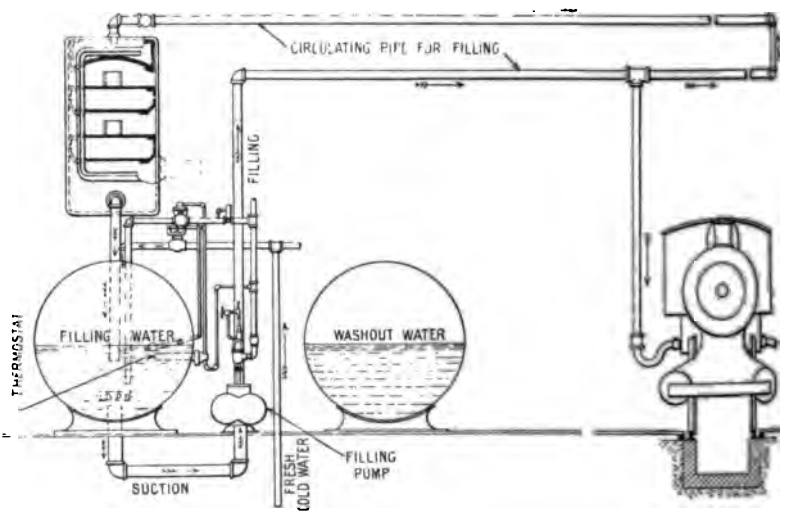


FIG. 13 ECONOMICAL SYSTEM FOR BOILER WASHING: BOILER FILLING PIPING

to boilers caused by too rapid cooling and obtaining additional work from the engine by reducing the time of standing, washing out with hot water is being considered on several railways.

31 *Casualty Office.* A notable feature in connection with the running department is the casualty office. Under the charge of a trained engineer, the function of this department is to collect reports from the running-shed staff of all engine failures, a failure or casualty being any defect in the working of the engine which causes it to lose time on the journey or to be late to its train from the shed. The head of the casualty office arranges for the proper classification of every case of failure and directs the investigation into each case.

ter careful inquiry the cause of the failures can be brought to the otice of those responsible for the design, materials and workmanship, eration, or purchase of coal, oil and other stores, the object always ing to promote efficiency in construction and improvements in eration rather than discover an offender. A good moral effect, owever, is created by thus constantly reminding all concerned of eir individual responsibility.

32 The summarized statements periodically made to the general anager and directors of all failures by which delay is caused to ains form a fair guide to the efficiency of the locomotives on the oad.

33 *Engine Cleaning.* In order that the examinations previously eferred to can be properly carried out, engines must be kept as lean as is possible at a moderate cost. On English railways, the eneral practice as regards engine cleaning is to employ boys from 4 to 19 years of age, who are afterwards promoted to firemen.

34 The method of payment for cleaning varies on different railways, day work, piece work and premium being employed, but day work is the most general. The piece-work system of cleaning was introduced some years ago on the Midland Railway, and was satisfactory until 10 years ago, when the larger types of engines began to make their appearance; the work of cleaning an engine then had to be divided, and this gradually led to cleaning by gangs on piece work.

35 Piece-work gangs being unsatisfactory and difficult to handle, about four years ago a system of cleaning engines on Rowan's premium system[1] was introduced at most of the large depots on the Midland Railway and is still in operation, although principally confined to the passenger engines. This system provides for a more methodical and thorough means of supervision, since each part of an engine, no matter how small, can be taken separately and, if passed, paid for on its merits without reference to other parts. The premium system has been satisfactorily applied by working the men in groups of four, each man being responsible for particular parts of the engine as set out on his job ticket. The premium earned by the men cleaning those parts goes to his account and has nothing to do with the earnings of the other men, thus preventing indifferent workers reaping the benefit of the industry of others in the group.

36 The premium system is successful inasmuch as it introduces a strong incentive to do more than had been, under other conditions,

[1]Proc. 1901, Pt. 4, p. 865; and 1903, Pt. 2, p. 203.

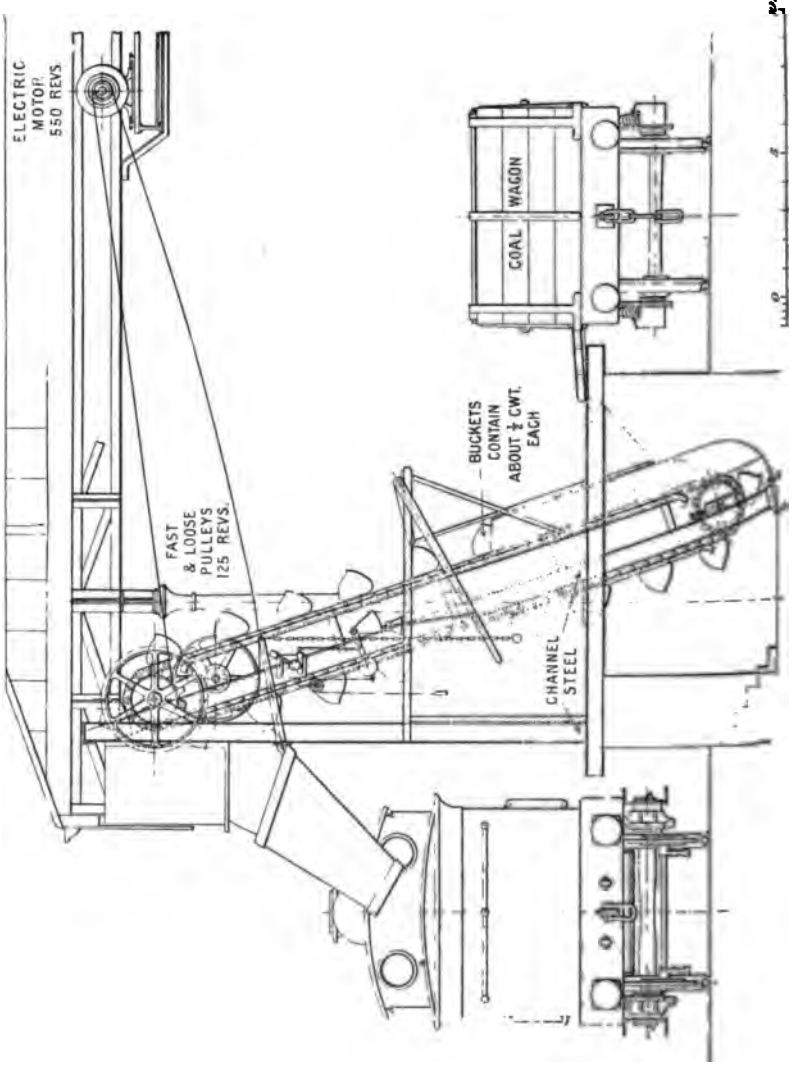


FIG. 14 COAL STAGE AND ELEVATOR, SHARP'S ORCHARD, G. E. & G. RAILWAY

nsidered a day's work. Cleaners working on premium are able supplement their weekly rate to the extent of 20 to 40 per cent. he arrangement of working the men in groups of four as a rule sures engines being ready for service as soon as they are required. ould the engine require cleaning in a shorter time than usual, ore men can be put on, each man with his work detailed on a job ket, without fear of the work being scamped. Under the piece-rk arrangement this was not easy to avoid.

37 *Shopping of Engines.* The engines are turned over by the nning department to the repairing engines department for heavy pairs, as a result of the condition of the various parts revealed the periodical examinations in the shed, but mainly as the result the periodical examination of boilers. The repairs to the boilers, a general rule, take longer than anything else, and the order of tting work through the shops is dependent on the time taken to pair the boiler. By making other repairs subservient to it, the gine is likely to be out of service for the least possible time. In lecting engines for repairs, consideration is given to the probable mands of traffic working, the heavy repairs to passenger engines ing undertaken in the winter months and to freight engines in the mmer. Roughly speaking, it is the practice on the Midland Rail-ay to overhaul in the repairing shops each passenger engine every 2 to 15 months, and each freight engine every 18 to 20 months.

38 The means described for examination, shed repairs, and shop-ing are those taken to ensure the efficient working of the locomotive ock. On the Midland Railway this efficiency is secured by the ithdrawal from service of about 25 per cent of the total stock. The ctual percentages work out at:

	Passenger	Freight	Total
n repairing shops	15.77	13.03	13.9
nder examination	1.36	0.95	1.08
topped for various repairs	8.57	7.55	8.08
ngines not available for work	25.7	21.53	23.06

39 These figures may be taken as fairly representative of British ractice. Having about 75 per cent of the total stock available for ork, its earning capacity, so far as it is controlled by the running epartment, lies mainly in the efficiency of the train arrangements.

40 *Arrangement of Engine Workings.* It is usual for the traffic epartment to provide in convenient form a statement of the train ervice for which motive power is required. The graphic form of the ime table is very suitable for this purpose, as by its use it is easier

to arrange economically the outward and return workings, and at the same time make provision for the most convenient places to change engines and ensure intervals during which the men can get their meals and attend to engine duties.

41 *Passenger Trains.* Several English railways divide their passenger train working into two classes: the first, generally the most important express trains, being paid on a basis of mileage, and the second being paid by the day.

42 *Links.* Suitable workings are grouped together in numbers varying from 3 or 4 to as high as 20, and the corresponding number of men necessary to work them are employed in rotation on each working. These groups are called links. Such grouping has the effect of dividing up the trains into two or three classes, which vary in their demands for power and correspondingly call for the use of different classes of engines. The grouping of workings is arranged in such a manner that the most powerful engines are kept as far as possible on trains where they are not extravagantly employed.

43 One of the main objects in the preparation of train arrangements before they are sent to the locomotive depots is to see that the maximum amount of the drivers' time is occupied in charge of the engines, and to reduce as far as possible the time during which the men are unemployed, or engaged in miscellaneous duties. On several railways charts are exhibited at each depot periodically, giving the classification of the drivers' time and how employed. These charts act as a very good check on the foreman's arrangement of the men's work, as it enables him to see at a glance whether the percentage of time in charge of engine is on the increase or decrease. It is advisable to have a link of such a size that it is large enough not to limit the drivers' knowledge to a particular road, but not so large that the knowledge gained of the various roads would be forgotten owing to the infrequent occasions the men work over the line.

44 In arranging links, due regard is paid to day and night work, and an effort is made to regulate the work so that a man is not continuously on one or the other. The men in each link work all the trains in it in turn, and any slight advantage in a particular week's work is, therefore, shared by all the men. When the links are arranged they are posted, for the guidance of the men, in a case at the engine shed, together with a complete list of the booked engine workings.

45 *Special Trains.* Special passenger trains are provided for in the weekly excursion time table. Arrangements are made at head-

arters for the various depots to work such trains, those having outward and homeward trip being generally worked by the depot m which the train starts, but in the case of additional or duplicate ins an endeavor is made to balance the mileage by utilizing an gine in one direction to work, and an additional train that may required in the opposite direction, or when duplicates are neces- ry over the same section from opposite ends about the same time, ey are dove-tailed in with the ordinary booked trains. The tim- gs of these special trains are supplied in a convenient form to the ivers working the trains. Such trains are worked by spare men men whose time is not fully occupied.

46 From the train arrangement sheets the "working engines ard," fixed in a convenient place on the shed wall, is arranged ily by the foreman in charge on the day or night shift, the trains ing shown in the order of running, and the engines allotted to work em, together with the information as to where the engines can found, that is, the shed or sidings where they may be standing. usually shows also all the engines due for examination or washing ut.

47 *Engines and Men.* As far as possible, engines are allotted to nd kept for the same drivers, and this is almost universally the rule in ie case of passenger engines on most English railways, but it has ot been attained as regards the freight engines at present (except ith the more important goods trains) owing to the uncertainty as to hen the engines of the ordinary goods and mineral trains will come to the sheds.

48 It would appear that the majority of the locomotive superin- ndents in England are of opinion that where first-class express work as to be done it is a distinct advantage to book an engine regularly the same driver. This practice extends on some lines to fast fitted oods trains, which require nearly as much working as an express. he experience on the Midland is that casualties are lessened owing o the greater care taken by the driver in working the engine and in roperly reporting defects; and as a result the coal consumption is enerally less.

49 *Working Results.* The necessary statistics for criticizing the esults of working of the various sheds are obtained in the following anner. Each engine driver at the end of his day's work makes out journal on which he enters in detail all trains worked by him, time ccupied in doing so, the route and description of train, and the aterials used during the day's work. These journals are handed to the time office, and the mileage is then entered to each trip, and

the weight of coal, oil, etc., is checked with the coalman and storekeeper's records in order to see that the entries made by the driver agree with what has actually been issued to him. From these journals the following statistics are compiled:

Engine hours.....Passenger trains
Engine hours.....Goods and mineral trains
Engine hours.....Shunting
Engine hours.....Assisting, piloting, ballasting, etc.
Ordinary passenger-train miles
Special passenger-train miles
Assisting passenger-train miles
Passenger shunting performed (calculated at 6 mi. an hr.)
Ordinary goods and mineral train miles
Special goods and mineral train miles
Assisting goods and mineral train miles
Goods and mineral shunting performed (calculated at 6 mi. an hr.)
Detentions to engines
Consumption of coal, oil and other stores by each individual engine

The time of engines employed exclusively for shunting purposes is calculated at 6 mi. an hour, from the time they leave the locomotive yard to the time they again reach the ash pit, with a minimum debit of 10 hours. Ballasting is calculated at the rate of 8 mi. an hour, but only the actual time occupied is brought to debit.

50 Engines standing as pilot, that is, to assist or work duplicate trains as required, are charged at the rate of 6 mi. an hr. for the actual time they are standing. A statement of mileage, wages, coal, oil, and stores consumed is compiled for comparing one depot with another. The compilation of these figures involves an immense amount of routine work; recognizing this the Lancashire & Yorkshire Company have adopted the Hollerith tabulating machine for the purpose, by means of which the following data are obtained:

Date
Shed where driver is stationed
Class of engine
Engine no.
Shed where engine is stationed
Driver's no.
Description of mileage
Miles run
Shed where coal is received
Weight of coal supplied
Description of lubricant
Quantity of lubricant supplied
Description of time
Time worked in hours and minutes

By means of the punched holes denoting the description, the e cards will show:

No. of train-miles run	Passenger, goods, mineral
No. of train-miles run assisting	Passenger, goods, mineral
No. light-engine miles run	Passenger, goods, mineral
No. locomotive shunting miles	
No. traffic locomotive shunting miles	
No. empty carriage miles run	
Quantity of locomotive oil supplied	
Quantity cylinder oil supplied	
Quantity tallow supplied	
Length of time men were in charge of engine	
Length of time men were traveling before or after being relieved	
Length of time men were engaged conducting, waiting orders, etc.	
Length of time trains were detained by signals, etc.	

se cards can be conveniently assembled to show cost of operating various sheds, classes of engines, classes of mileage, etc.

APPENDIX NO. 1

TABLE 1 MIDLAND RAILWAY. EXAMINATIONS OF ENGINES BASED ON TIME AND MILEAGE

Parts of Engine or Tender	Remarks	Passenger			Freight				Shunting Engines
		Nos. 4 and 3 Class 4-4-0	No. 2 Class 4-4-0 0-6-4	No. 1 Class 2-4-0 0-4-4	No. 1 Class 4-2-2	No. 3 Class 0-6-0	No. 2 Class 0-6-0 2-6-0	No. 1 Class 0-6-0	0-4-0 0-6-0
Boilers	Must be thoroughly examined inside and outside, and tubes taken out.	New boilers when they have been at work 5 years, afterwards every 4 years (as per printed instructions of January, 1900)							
	Fire-box, tubes, tube-plates, stays, brick-arch, smoke-box, etc., must be examined.	3 to 5 weeks							
	Lead plug in fire-box roof must be changed.	6 to 10 weeks							
	Lead plug in fire-box roof must be examined.	3 to 5 weeks							
	Safety-valves, spring-balances, and connections must be examined	9 to 15 weeks							
Gage frames and trial taps	Gage-frame taps, gland nuts, top nut, etc., and trial taps must be examined and left free, and water-ways thoroughly cleared out.	3 to 5 weeks							
Injectors	Injector steam plug (old pattern), combination steam and stop plugs, cones, and clacks must be examined.	3 to 5 weeks							
Spring for reversing lever catch on goods-engines, also racks and triggers	Must be thoroughly examined to detect weak or otherwise defective springs, or wear in racks and catches.	10 to 18 days							
Brake, also tender brake cylinder attachments	Disc-valves, relief-valves, ejectors, pipes, including intermediate hose-pipes, drip and clappit-valves, and everything connected with the steam and vacuum brake must be thoroughly examined.	3 to 5 weeks							
Tender water gages	Must be examined.	5 to 9 days							
Axle-box oil pads	The pads of axle-boxes with doors should be examined and cleaned.	5 to 9 days							
Steam sand-pipes and valves	Must be examined.	3 to 5 weeks							
Furnace lubricators	Must be examined.	Mileage 4000 to 4700				3000 to 3700			

Parts of Engine or Tender	Remarks	Nos. 4 and 3 Class 4-4-0	No. 2 Class 4-4-0 0-6-4	No. 1 Class 2-4-0 0-4-4	No. 1 Class 4-2-2	No. 3 Class 0-6-0	No. 2 Class 0-6-0 2-6-0	No. 1 Class 0-6-0	Engines 0-4-0 0-6-0
		Mileage							
Big and little ends, connecting-rods, crank-journals and webs, outside coupling rods	Straps, brasses, gibs, cotters, bolts, etc., of big and little ends must be taken down and thoroughly cleaned and examined, and connecting rods, crank journals and webs, and outside coupling rods thoroughly cleaned and examined.	4000 to 4700					3000 to 3700		
Tender tanks fitted with water scoop (including water scoop indicator gear)	All tender and side tanks must be emptied, cleaned out and examined, and valves, strainers, rods, stays, pins and connections examined.	4000 to 4700					3000 to 3700		
Tender tanks not fitted with water scoop	All tender and side tanks must be emptied, cleaned out and examined, and valves, strainers, rods, stays, pins, and connections examined.	12,000 to 14,500					9000 to 12,000		
Axle-box oil pads	All under-caps, and axle-boxes with pads in (except bogie-boxes, which are examined between the limits shown below for bogies) must be taken down, cleaned out, and the pads made right.	16,000 to 19,000					9000 to 12,000		
Piston-valves, pistons and cylinders	Valves must be taken out and examined, the steam and exhaust ports and blast-pipe cleaned. Pistons must be taken out, and rings, piston-heads, and cylinders examined.	20,000 to 24,000		12,000 to 14,100	20,000 to 24,000		15,000 to 18,500		
Slide-valves	Must be taken out and examined and thickness noted, steam and exhaust-ports and blast-pipe cleaned.								
Valve-spindles	Must be examined for defects, especially at cotter-hole, and that it fits along its cone length in the guide socket properly, also that the leading end fits properly in the valve cover bush.								
Engine and tender bogies	Bogies must be taken out, taken to pieces, and thoroughly cleaned; also springs, journals, and every detail carefully examined, and centers and rubbing surfaces lubricated.	20,000 to 24,000					15,000 to 18,500		

Note.—Whenever an engine is stopped for such repairs as will take a day or two or longer before it is put to work again, the district superintendent, his assistant, or R. E. foreman must finally, before the engine is handed over to the W. E. foreman for work, personally make a complete examination of the engine, trying and tapping all bolts, cotters, cotter-pins, rods, etc., to see that they are not only in a proper position, but that they are not loose or worn in any way. Holes and bolts in small rods and pins of same, such as damper gear, cylinder-cock gear, must be carefully noted, and before the engine is allowed to start work any defects must be made good. A record is to be kept by the district locomotive superintendent of every engine thus examined, and it is to be produced when required. The examination must be thorough and complete, and carried out by the district superintendent, his assistant, or R. E. foreman.

No. 1290*b*

HANDLING LOCOMOTIVES AT TERMINALS

By Frederic M. Whyte, New York

Member of the Society

INTRODUCTION

2 Detail methods in the handling of locomotive terminals vary so ely that the scope of this paper has been limited to well-established ctices along certain definite lines, in the United States and Can-, with some personal suggestions. Steam locomotive terminals ıe are sufficiently developed to permit of extended discussion.

3 Terminals differ very much in importance and the paper will confined largely to the more important onès, leaving it to the ıgment of the reader to decide what parts apply to the smaller ter-ıals. By the designation "important terminals" is meant those ing for about 100 locomotives during each 24 hours.

LOCATION OF TERMINALS

4 Starting with a terminal at each end of a railroad the interme-ıte terminals are located as the topography of the line, the location important towns, or other factors, may indicate. Some years ago e distance between locomotive terminals was shorter than is con-ered desirable now, and generally the divisions have been length-ed so, that at the present time they range in length from 100 miles 200 miles; divisions approximately 150 miles in length are quite ımon. Frequently there are locomotive terminals between the ision extremes, but these are usually for local and suburban runs d are of lesser importance, although a few years ago they were the portant terminals.

5 From the standpoint of operation, the engine-house and its essories at the divisional point should be located close to the freight

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resented at the meeting of The American Society of Mechanical ıneers with The Institution of Mechanical Engineers, Birmingham, gland, July, 1910.

yard, for freight locomotives, and to the passenger station, for passenger locomotives. This condition is more readily fulfilled for freight than for passenger service. For the latter it is sometimes necessary to place the engine-house five to ten miles from the passenger station where the locomotive is detached from the train. This requires the introduction of separate crews for handling the locomotives between the engine-house and the station and also necessitates exceptional methods of inspection and reporting and calling the crews and equipping the locomotives for the next trip. Such conditions exist at Buffalo on the New York Central & Hudson River Railroad. On the other hand, if the station is not a terminal of the road the through trains may be stopped near the engine-house and the locomotive detached and attached there; such is the method on the Lake Shore & Michigan Southern Railway at Cleveland.

APPROACH TO THE TERMINAL

56 The route between the train terminal and the engine-house should be as direct as possible and independent of all other movements. This is not always possible, however, and in passenger service more particularly, the route is largely made up of main line track. Especially is this true when the locomotive terminal is at some distance from the station.

LINE OF SEPARATION OF RESPONSIBILITY

57 So far as concerns the mechanical operation of the locomotives the mechanical department must be responsible. There are two well recognized and quite different forms of railroad organization: the departmental, in which the mechanical department has supervision over the design, maintenance and mechanical operation of the locomotives; and the divisional, in which the mechanical department has supervision over the design, construction and general condition of the locomotives, and the transportation department has supervision over running, maintenance and mechanical operation. In either of these organizations the responsibility for the locomotives must change, so far as individual officials are concerned, at some place adjacent to the engine-house. In some organizations where this change is made at the turntable, or its equivalent, there are a very limited number of rectangular engine-houses, notably at the St. Louis passenger terminal, where a transfer table is used and a turntable is not necessary

In these organizations the official in charge of the engine-house, who is a part of the mechanical department, has supervision over the movement of the locomotives between the table and the house and over the locomotives in the house; and the coaling plant, ashpit and other accessories are handled by the transportation department. In other organizations the engine-house official has supervision over the entire engine-house premises, including the coaling plant, ashpit and all other accessories.

58 It is not well established which is the better organization, and not only does the organization differ on different roads, but often the same road has changed several times from one arrangement to the other. It is probable, however, that the best arrangement is the one which provides the highest class official nearest to the place to be handled. The best results probably will be obtained from the present tendency to place a master mechanic at each of these important locomotive terminals and assign to him supervision over the entire plant. Such an arrangement will place the line of separation of responsibility for incoming locomotives on the approach to the engine-house and outside of the coaling plant; and for outgoing locomotives at the track assigned for locomotives ready for service.

SEPARATION OF LOCOMOTIVES ON A DIVISION

59 On a division having only one important locomotive terminal it is not necessary to designate where the important repair work will be done, but on many divisions there are two or more engine-houses thoroughly equipped for the complete maintenance of a certain number of locomotives, and on these divisions it is necessary to designate those which will be maintained at each house. Each engine-house will do the periodic work and the running repair work on the locomotives assigned to it, and the inspection and safety repair work on any locomotive which is run into the engine-house. The assignment of the locomotives to the different houses is made by the divisional mechanical officer, usually designated as master mechanic. There is more or less transference of locomotives from one division to another for temporary service, but there are serious objections to this, especially when the periodic work and reports are to be considered, and when the duration of the temporary service is more than a few days. On the large railroad systems it seems quite necessary that an individual locomotive record of periodic inspection and work be kept by the divisions and the transferring of locomotives from one division to

another for a week or two results in annoyances, errors and loss of records incident to transferring records when the locomotives are transferred.

LAYOUT OF A LOCOMOTIVE TERMINAL

60 It is not the intention of this paper to cover this item in such detail as would be necessary for the preparation of an ideal layout but rather to deal in generalities which may be of greater interest in an international discussion. It will be in order to consider, first, the capacity of the various facilities which are to be supplied. It is desirable to rate the capacity on the maximum demand for comparatively short interval of time, say one hour or two hours, for the coaling, ashplant, turntable, water and sand facilities; and for longer periods of time for other facilities. Some of these ratings may be consistently higher than the sustained rating of 24 hours. There should be considered also, how much of the terminal will become inoperative in case of accident to any one of the important units of the terminal, and the approximate length of time the resulting disorder may continue; and to provide the necessary assurance of continuous operation, by the installation of duplicate units. The water and coaling plants and the turntable are the most important units and these will need special study.

61 Water columns are usually so well distributed at a division terminal that only a failure of the entire water system need cause much delay, so that the important consideration is convenience of location. The insurance may be taken care of in the general water system. An ample supply of water is also of prime importance.

62 For insurance of the coaling operation there may be selected one of several schemes, one of which is to place the cars of coal on one of two or more adjacent tracks and the locomotives on another, transferring the coal from the cars to the tenders by hand or by locomotive crane. Another scheme is to coal the locomotive at the coaling stocking plant, if one is near by; or by other means, none of which seriously affect the general arrangement of the locomotive terminal.

63 On the contrary, insurance of turntable service will very decidedly affect the general layout of the terminal because the spare table must be capable of serving the whole or a considerable part of the engine-house capacity, inasmuch as failure of one table may occur when a large number of the locomotives are in the house served by

The only way in which more than one turntable can serve one unit of engine-house capacity, in a circular engine-house, is by dividing the house unit into parts and having a turntable for each part. To accomplish this result it is considered very good practice to limit the size of a separate engine-house to approximately a half-circle, and to provide any additional capacity in another half-circle, offset from the first at least enough to permit of a separate turntable for each. The separate turntables should have track connections to the inbound and outbound tracks, and usually have inter-connecting tracks.

64 For further insurance of uninterrupted turntable operation two motors for revolving each turntable are considered desirable, and even necessary, but both should not be operated from the same power plant. Sometimes two gasolene motors are used, and sometimes one electric motor is provided for general use and a gasolene motor for emergency use.

65 If the house is made up of parts of two circles, one end of each part will be placed near one end of the other, and the machine shop, storehouse, power house and offices will drop in very naturally between the two. The drop pits, overhead crane, and other special facilities necessary in a limited section of the engine-house, will be placed convenient to the shop.

66 There remain to be located only the coaling plant, ashpit, sand house and water columns, which will be placed primarily for convenience in getting the inbound locomotives to them. There must be ample water facilities on the outgoing tracks and it is desirable to have a small ashpit and a sanding place on these tracks. If provisions are made to get the outgoing locomotives to the coaling plant on special occasions, then a coaling place is not necessary on the outgoing track. Of these facilities on the inbound tracks the ashpit will be nearest the turntable so that the locomotives may be moved the shortest distance when there is little or no fire on the grates. Sometimes it has been thought desirable so to arrange the facilities that coal, water and sand can all be taken at the same time; but if the hostler is to stay in the cab so as to be ready for moving the locomotive promptly, it is probable that the difficulty in arranging these facilities for the various lengths of locomotives will make it desirable to place them somewhat more than a locomotive length apart if the ground space permits. Sometimes a track arrangement is made that permits of advancing one or more locomotives around other locomotives, and when the ground space is available this is a good thing to do. The tracks on which the ash

cars are taken to and from the ashpit should be independen inbound and outbound locomotive tracks.

THE ENGINE HOUSE

67 The cross-section and other details of construction engine-house have such important relations to the prompt h of locomotives at terminals, especially in the colder climates is well worth while to refer to them.

68 The two items which have been given most considerat ing the last few years, for houses located in the colder clim the heating and the ventilating; they are so closely related t should be considered together. For low cost of heating, the the cross-section should be as small as the locomotives wil and until recent years it was the practice to follow this pri the design. Unfortunately, good ventilation, which is equall tant, has not been obtained with the small cross-area and as the condition of fog and smoke, and principally fog, in these lo houses in cold weather is such, at times, as scarcely to be un until seen.

69 A decided improvement in ventilation has resulted fr ing part of the roof somewhat higher than the necessary h would require, placing the ventilators at the top of this higher The design of these ventilators is undergoing a process of ment and at present practically each road has its own preferre An advantage of this high roof section is that additional area dows is given in the enclosing wall, and this additional li important for the wider houses now necessary.

70 In the effort to reduce to a minimum the fog in the cold weather, special efforts are also made to prevent the e steam from the locomotives. To this end a pipe line of large is placed around the house, usually above the locomotives, minals conveniently arranged for making quickly a pipe co to a valve in the top of the boiler. To reduce the steam pr a boiler the steam is blown through this pipe into the atm or to water-heating tanks or hot wells.

71 Pipe lines, including cold-water, hot-water and stea are similarly arranged for washing out boilers, and provision mixing the cold water with hot water or steam to get the desi perature for washing. The same pipe lines, or others, con water from the boiler to storage tanks and reheaters. The

jacks have elongated bases which cover the safety valves as well as the stack.

72 The heating is done by one of two methods: by direct radiation from steam pipes placed on the side walls of the pits; or by hot-air blast. Probably the latter is preferable. The place of delivery of the heat is as near the locomotive as possible. The capacity for the steam heating is usually all that can be obtained from two to six 2-in. pipes on each side wall in the pit and some on the outer wall of the house; for the hot-air system the capacity is the volume of the house every ten to fifteen minutes, at a temperature of about 60 deg. fahr. A very important point about heating engine-houses is to keep the doors and windows closed and to cover the usual openings at the bottom of the doors. It is desirable also that the roof timbers be so placed as not to interfere with the flow of air upward along the roof to the ventilator outlets.

73 It is the general practice to provide several tracks in the house, with a drop pit into which to drop driving and truck wheels, and to provide in the same section of the house an overhead crane for loading to and unloading from cars these wheels, and for handling air pumps, cabs, boiler fronts and other heavy parts to and from the locomotives. Light portable cranes are provided for lifting steam-chest covers, rods, and other heavy parts which do not require high lifts.

74 There are many smaller details about engine-house design and equipment which contribute to the rapid and efficient handling of locomotives, but it will be best not to burden the paper with them.

THE COALING PLANT

75 The uninterrupted operation of this plant is of prime importance, and with this in mind, that design should be chosen which is least liable to be deranged and which can be repaired most quickly. With sufficient ground space available, these considerations will make the choice a trestle, so that cars of coal can be pushed or hauled up an incline and the coal dumped direct from the cars into the bins from which it slides by gravity into the locomotive tender. This kind of plant reduces to a minimum the breakage of fragile coal, sometimes an important feature. If the incline approach is too steep for steam locomotive operation, the motor and winch should be in duplicate and the motors not dependent upon the same source of power, unless there is little chance of total disability of the source

76 When the ground space is limited the mechanical hoisting plant, of the bucket or a similar type, is a necessity, and it has been selected sometimes when the available space would permit of a trestle. There are various forms of the mechanical plant, but it will be unnecessary to consider them in detail. Usually they are placed crosswise of the tracks. Sometimes the same apparatus used to elevate the coal is used to convey ashes from the pits and to deliver them into storage bins or into cars. This combination has the advantage of concentration of facilities when such concentration is necessary, but there are objections to it otherwise. To give the necessary capacity at the coal pockets and ashpits a greater number of tracks are necessary and the risk of personal injury from coal falling from the tender and striking the men who must be about the ashpit is increased. This concentration will shorten and widen the approach to the engine-house.

THE ASHPIT

77 It is desirable to have a pit capacity immediately beneath the locomotives for several hours' busy dumping of pans and grates, whether the ashes are handled by hand or by machinery from the pit to cars. If handled by hand this is to provide for economical time distribution of labor; if handled by machinery, to provide for continuous dumping when the machinery is out of order. The economical transferring of ashes from pit to car by hand requires a lower pit for the ash cars, adjacent to the ashpit, and sometimes conditions do not permit of such an arrangement or of the necessary track approach. If the ash pan and fire cleaners can be used for transferring the ashes from pit to car, at intervals when there are no pans or grates to be cleaned, the manual labor can be most economically distributed. The mechanical plants usually operate crosswise of the pit, limiting the length of pit undesirably, and making necessary several pits side by side or a further mechanical installation for transferring the ashes lengthwise of the pits to the cross conveyor. With each addition to the mechanical devices, complications are multiplied. Water hydrants for hand hose are located conveniently about the ash pits, and shelters are provided near by for the men to occupy when there is a lull in the work.

THE SANDING PLANT

78 The location of the sand-drying plant should be convenient to the inbound tracks, but not necessarily adjacent to them. Convenience

elivering wet sand to the drying plant is important. As air pres- is used to elevate the dry sand to the storage bin from which it by gravity to the locomotive sand box, air pressure can also be l for transferring the dry sand for some distance horizontally, so the place of delivery for the wet sand may be conveniently ıted for such delivery. Sometimes the sand is dried on steam- ted tables, but since the temperature cannot be raised high enough satisfactory drying, the preferred dryer is the stove. The dry sand , from which the sand is delivered to the locomotive, is usually ıted between the coaling plant and the ashpit.

WATER SUPPLY

9 Water columns should be conveniently located on both in- ınd and outbound tracks.

THE ORGANIZATION

0 *The Master Mechanic.* The usual divisional organization ces one man, the master mechanic, in charge of the locomotives the division, both when the locomotives are away from the engine- ıse and when at the engine-house. One of the division terminals ınder his supervision and his headquarters are generally at that ninal because it is the important point of his jurisdiction. He may 're assistants with duties both at terminals and between them, and always has assistants who confine their efforts to the terminal, l others who confine their efforts to the road work. If at the isional terminals the freight locomotives and the passenger loco- tives are separated, as is often the case, one assistant may have ervision over freight locomotives and terminals, another over senger locomotives and terminals, and a third over the inter- liate division engine-houses, in which both passenger and freight motives may be cared for.

1 *Traveling Foremen.* The assistants in the operation on the d are usually designated as traveling engineers or road foremen engines, and traveling firemen. Some are assigned to passenger vice and others to freight service, and they report to the master chanic, or if there are assistant master mechanics, then to the proper istant master mechanic. Their duties are, nominally, to instruct engine drivers and the firemen; to report the conditions of the loco- tives as delivered from the engine-house; to foresee, when possible,

and to report work on the locomotives which may require special preparation or special attention for the preparation of material, etc. Too often, and it may be said usually, they are kept busy ascertaining and reporting what has already happened and explaining it, whereas their efforts should be directed to preventing the repetition of undesirable occurrences. It is conceded, however, that a general knowledge of what has happened and the causes is essential for the intelligent direction of means for preventing recurrence.

82 All of these officials, from master mechanic to traveling firemen are subject to call at any hour.

83 *Engine-House Foremen.* The organization at the locomotive terminal will begin with the general foreman, who will have general supervision of the terminal 24 hours a day and seven days in the week. He will have personal supervision in the daytime; the assistant general foreman will report to him and have supervision at night. These two may arrange between themselves, subject to the approval of the master mechanic or the assistant master mechanic, for regular rest days. The division of the 24 hours between these two men means somewhat more than 12 hours a day service for each, that there may be time for the necessary consultation between them. Because of this and the fact that the change in supervision is made in the morning and evening, the busiest hours at most engine-houses, and at about the same time the other employees change shifts, there is being considered, and in fact put into operation at a few places, an arrangement for 8-hour shifts, so assigning the terminal men that the entire shift will not change at any one time. In such an arrangement the general foreman would be present during a part or the whole of every shift and one of his three assistants would be assigned to each shift. Twenty-four-hour operation is necessary at engine-houses and two complete breaks in each 24 hours are not conducive to best results, nor can man deliver his best efforts for 12 hours a day continuously. Hence the tendency to shorten the hours of daily service and to minimize the effect of each change of shift.

84 In addition to the assistant general foreman, the store-keeper and chief clerk will also report to the general foreman. To the assistant general foreman in charge of each shift, the yard foreman, the house foreman, the shop foreman, the foreman of laborers, the dispatcher and the necessary clerks, will report.

85 *The Yard Foreman.* He should have complete charge of the locomotives at the terminal and outside of the house. He should take from the house foreman instructions as to the particular stall in which

each locomotive is to be placed and report as soon as it is placed; and should take from the despatcher instructions about delivering the locomotives to the transportation department. This arrangement will place under the supervision of the yard foreman, the coaling, sanding, watering and ashpit plants, and the turntables; the care of the locomotives which are standing outside of the house; and also the special crews that run the locomotives between the engine-house and the train terminal, when such crews are necessary.

86 *The House Foreman.* He should have supervision over the workmen in the house, and over the inspectors on the incoming track, if there are such inspectors. The various foremen reporting to him are those in charge of repairs to tenders, boilers, machinery and air brakes, and others similar, depending on how far the work is specialized. In working out the 8-hour shift arrangement, it has been suggested that there be assistant house foremen, each with supervision over certain stalls assigned to him; the special work, however, such as air brake and similar work, to be done by special gangs for all the stalls. The shop foreman will also transfer machinists, boiler makers, etc., from one assistant foreman to another, as conditions may demand. This arrangement of dividing the house into sections, each in charge of an assistant foreman, is being used with satisfactory results. It makes of the assistant foreman a high-class inspector because it places him in such close touch with the conditions that he can say just what work should be done, and know how thoroughly it is done. This is a most important consideration because the engine men and inspectors may report a lot of work to be done, partly to clear themselves, as well as to inform the foreman thoroughly. The man who does the inspecting and repairing on a locomotive or on a number of locomotives day after day, is well informed on what must be done and how it should be done; which leads to the suggestion of the further step that the maintenance of certain locomotives be assigned to certain gangs. This ought not to be impossible in passenger locomotive terminals.

87 *The Shop Foreman.* The importance of the shop foreman depends largely upon the importance of the shop. Sometimes his duties are assumed by the engine-house foreman. The tendency seems to be in the direction of providing larger shop facilities, and as these are increased the importance of the shop foreman will increase.

88 *The Work Report Clerk.* The clerical force perform the usual duties of such employees. There is one clerical position, however, which is growing in importance and the qualifications for the filling of which are becoming more and more exacting: this is the position of

work report clerk. He should understand clerical work and know enough about locomotive parts and repairs to make out a satisfactory report of work to be done. He first comes into contact with the arriving engineman, who reports on conditions which can be observed only when the locomotive is in action. Enginemen do not like to write, hence their written reports are short and unsatisfactory. The tendency at present therefore is for the clerk to write these reports for the signature of the engineman and the clerk must understand what work is necessary and report it properly. As the clerk is almost always accessible, the information is thus available in case further explanations are required. This clerk also makes a record of the incidents of the trip as reported by the engineman, so that in case of inquiry, the desired information is already on file.

89 The engineman's report of work to be done and the report of the inspector should reach the work report clerk at the same time, that there may be no delay in distributing the work to the respective gangs.

90 *Bulletin for Completed Work.* Quite as important as having the work to be done promptly reported to those who are to do it, is the reporting back promptly when the work is completed, and to have this information easily available for those who need to have it. For this purpose various arrangements are provided, the details being worked out to suit the peculiar layout of each house. The essential features are provided by a blackboard located conveniently for those who make the records and for those who must read them. This board is ruled into vertical columns, one for the number of the locomotive, one for the number of the stall in which the locomotive is located, and other columns, depending upon how the work in the house is distributed among the repair men. For instance, there may be a column headed "air brake," another "boiler," another "machinery." As each class of work is completed each foreman marks on the board in the proper column and opposite the particular locomotive number his "O. K.," indicating that his work on the locomotive has been completed. When all the spaces opposite a locomotive number are marked "O. K.," it is evident that the locomotive is ready for service. The record is erased as soon as the locomotive is taken out of the house. The convenience and despatch with which these records can be made are important factors.

91 *Outfitting the Locomotive.* Contrary to the previous practice of requiring the locomotive crew to do some cleaning, fill oil cups, and in general look after the outfitting of the locomotive, the present ten-

:y, and it is pretty well established, is for the engine-house force utfit each locomotive completely for service on the road. There ains for the crew, of course, the responsibility of knowing that necessary repairs and outfitting have been done, even though the motive is delivered to them at the station.

The Despatcher. It remains for the despatcher to know what motives and crews are arriving, and to care for the proper des-:hing of locomotives and crews.

POOLING

Some years ago it was the general practice to assign a locomo- to a crew and both crew and locomotive to particular runs, and n the locomotive was taken to the shop for repairs the crew worked ıe shop until the repairs were completed, usually devoting much ll of its shop time to its locomotive. At that period there were extra passenger runs and the freight runs were very largely duled runs, under which conditions it was easy to assign locomo- ; to crews and crews to runs, keeping each crew on its particular motive and run. As the maximum freight service increased and fluctuation between maximum and minimum freight service :ned, it became necessary to move a large proportion of the freight ıs as extras, which made it quite impossible to assign crews and motives to runs not scheduled. It was also necessary to increase) decrease the number of locomotives in proportion to business ands, which could be done only by withdrawing locomotives from ice, during which time there would be only the interest and depre- on charges on them.

As a result a plan was developed to increase the service of .ocomotives by placing any crew on any locomotive for service, :ad of holding it until its assigned crew could obtain the necessary

While this prevented the assignment of locomotives to crews it e possible a larger individual locomotive mileage per month or year. The first experience with this arrangement in freight ser- seemed so satisfactory that it promised well for passenger ser- to which it was extended, so that a locomotive used one day on train would be used the next day on a different train, permitting operation of a certain number of trains per day with greater or number of locomotives than trains. The idea, of course, was to ate a number of trains with a less number of locomotives.

The criticism most generally made upon this system is that personal interest which the man had originally in his own loco- ıve is lost. This has been valued very highly by some officials, e particularly those of the motive power department, and less

highly by others, usually of the transportation department and more particularly those who are not so well versed in the trials and tribulations of the motive power department. Under the pooling system the effort of the average crew is to get through with the particular locomotive as quickly and as easily as possible and to let the next crew get along as best it can.

96 Such conditions necessitate careful watching of the reports from the enginemen so that everything that the engine-house inspector cannot well find is included, and also careful inspection and repairing at the engine-houses. It may make necessary also, an additional expense per locomotive for wear and tear, as some argue, and at the engine-houses, as others argue; but whatever the cause or amount, this additional expense is the cost of getting the additional mileage per locomotive per month or per year, and it is a question of whether the cost is more than offset by the gain. The argument that it is as well to get the mileage-life of a locomotive in fifteen years as in ten neglects the fact that possibly 50 per cent more locomotives will be required if it is gotten in fifteen years than if in ten years, with a resulting interest charge.

97 Possibly, also, those who hark back to the times of assigned locomotives and crews and picture to themselves the enginemen setting box wedges and rod brasses, adjusting the piston rod packing and doing a long list of other work, overlook the difference in the size of the parts of present and past locomotives, and that a crew even if it knew a certain work was required and was willing would be unable to do it, at least alone. Extensive experiments have been made to determine the relative costs of the assigning and the pooling systems and in some of these experiments at least, no material difference in cost has been found. However, there may be, and probably is, some loss in reliability of service in pooling.

98 The fundamental idea of pooling is to obtain from each locomotive the maximum mileage per month or per year, in other words to keep the locomotive going, and various schemes have been devised to accomplish this and to obtain at the same time any advantages there may be in the personal interest of a crew in its own locomotive. One of these is to assign one locomotive to two or, at times, three crews, each crew making a round trip from terminal to terminal. A variation is to change the crews about midway in the trip; this has some decided advantages, the principal one being that a fresh crew is obtained at the beginning of each quarter of a round trip, or each half of a single trip, and while the rest at each terminal is not of long

ion, yet it means much to the crew, especially in hot weather; inasmuch as the crew is not at home at the divisional terminal, ien are anxious to start back so that they may reach home. To out satisfactorily this system of changing crews at the middle ivision, it is necessary that the divisions be so arranged, or of length, that there shall not be too much constructive mileage ie crew; that is, that the mileage for which the crew is paid shall e materially more than the actual mileage made by it.

Since it is quite certain that a locomotive in proper condition rvice can be used a greater number of miles or hours per week month than one crew is able to stand, it would seem to be good r to get full returns in some way and not limit the output in or in hours service to the capacity of the crew; on the other , the men must be given proper consideration and be permitted ıke fair wages. The pooling of locomotives and of crews in the ent kinds of service makes it possible to use each locomotive the num number of miles in a certain period of time, which maximum ıe about the same as for any other locomotives in the same ser- granting, of course, that nothing serious goes wrong with it; ɔ makes possible maximum and equal earnings by men of physi- quality.

) The assigning of one locomotive to one crew limits the output ned from the locomotive during a month or a year to the capac- f the crew; assigning one locomotive in road service to two or regular crews need not limit the output of the locomotive but place the earnings of the crew below its ability and below aver- arnings for similar work. In yard service it is possible and is the al practice to assign one locomotive to two crews. If in road :e one locomotive is assigned to two or more crews, the run d be arranged to permit each crew fair earnings. Another varia- f the pooling system is to assign two locomotives to three crews, ıich resort may be made when two crews on one locomotive ıt make the average earnings.

It will be noted that the original idea of pooling was to obtain num mileage from the locomotives, which resulted, apparently, ing from the crews and placing upon the engine-house a large part responsibility of the condition of the locomotives; then appeared ions which had in view this original idea, coupled with the effort ce upon the crews at least a part of the responsibility for the ion of the locomotives taken from them or voluntarily given r them under the straight pooling system; each arrangement g in mind a fair earnings return to the crews.

No. 1290c

ENGINE-HOUSE PRACTICE

)LING LOCOMOTIVES TO SECURE CONTINUOUS OPERATION

By F. H. Clark, Chicago

Member of the Society

The topic assigned me is so comprehensive as to embrace all features of engine-house practice. In order to get the er clearly before the meeting, therefore, it may be desirable to ibe briefly such features of design and equipment as are con- d good practice in the United States.

ARRANGEMENT OF LOCOMOTIVE TERMINALS

The engine-house and its appurtenances should be located, possible, at a point near the yard or station where the engines eleased or required, though the plan must usually be adjusted to existing conditions of topography or space. In Fig. 15 is shown n which may serve as a basis of the paper. It has no unusual res, but it may be considered a fair example of engine-house ice. Some space might be saved by the use of a different design ider pit, and considerable space by a different coaling station. r modifications would naturally suggest themselves in consider- he application of the plan to any specific case.

The approach to the engine-house provides two tracks for ning engines, one on either side of the coaling station, and one for outgoing engines; though connections are provided by which novement may be varied if necessary.

The coaling station indicated on the plan is of a design fre- tly employed in locations where space permits. Fig. 16 shows its

sented at the meeting of The American Society of Mechanical neers, with The Institution of Mechanical Engineers, Birmingham, nd, July 1910.

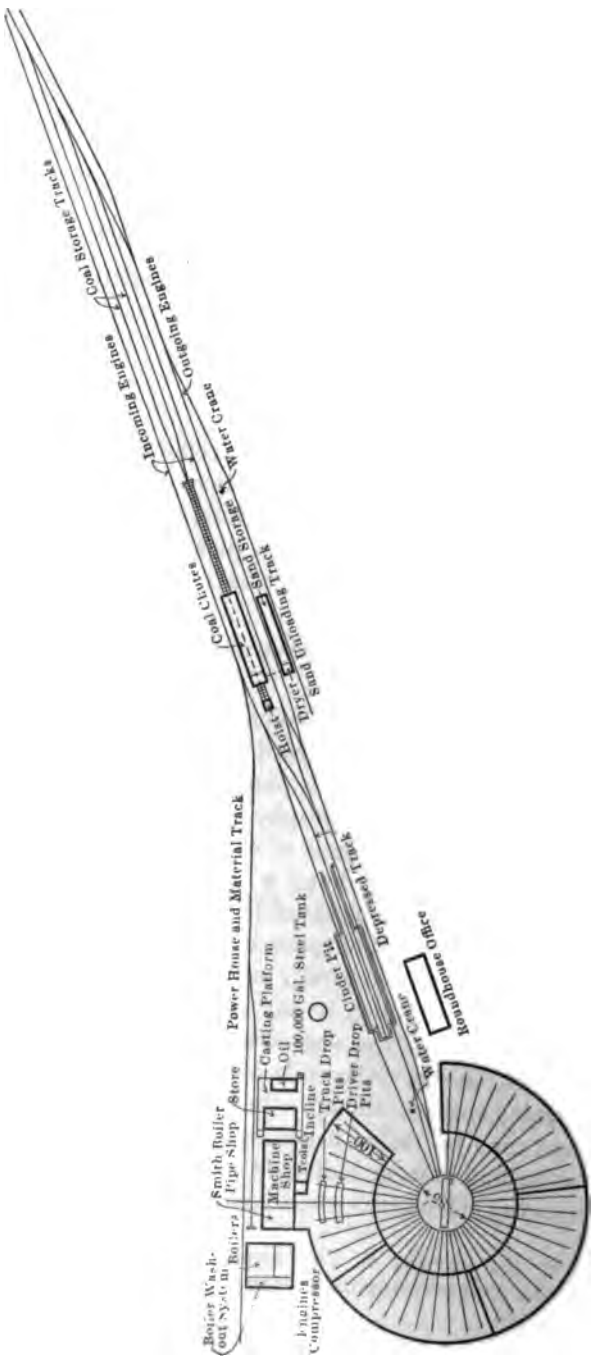


FIG. 15 ARRANGEMENT OF LOCOMOTIVE TERMINAL

onstruction, but with the tracks at right angles with the
ıe of the structure, instead of parallel to it, as in Fig. 15. The
tation illustrated is of 700 tons capacity. The coal is ele-
cars by means of a hoist which pulls the loaded cars up a 20
incline at a rate of about forty feet per minute. The coal is
or dumped out of the car directly into bins or pockets, if
is unnecessary; or on a grating of breaker bars spaced four
hes apart, through which the coal drops when broken. The

FIG. 16 COALING STATION WITH TRESTLE

elivers coal to six tracks, five underneath and one at the end.
may be operated by steam or gasolene engines, or by elec-
rs, motors being usually considered preferable where elec-
nt is available.

nother type of coaling station is shown in Fig. 17. This
as an overhead storage capacity of 1200 tons, and the con-
is entirely of steel and concrete. The coal is hoisted in a
olmen counterbalanced buckets, and distributed in the bin by

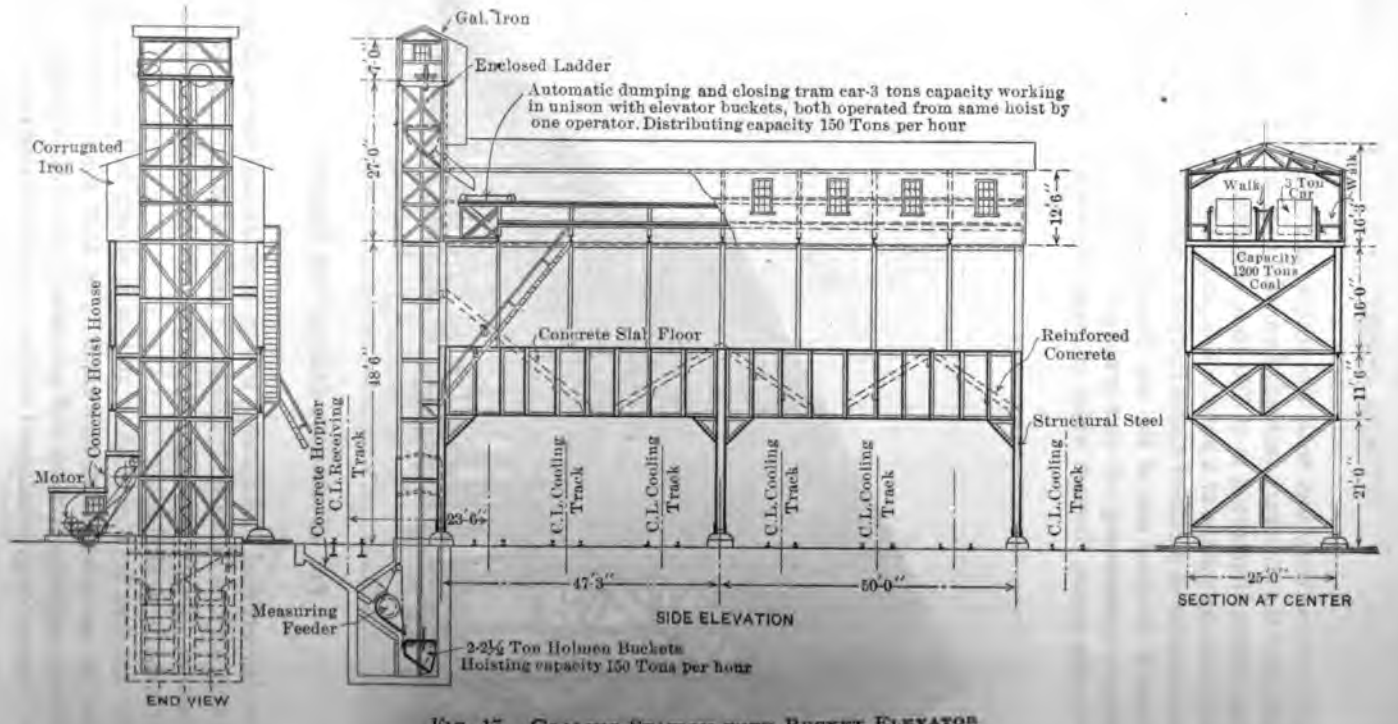


FIG. 17 COALING STATION WITH BUCKET ELEVATOR

special automatic tram car. The coal is received at one bin and is delivered to five coaling tracks, four underneath and one adjacent. To facilitate the handling of cars of coal winter, three additional receiving hoppers are provided, so ·ozen in the bottom of the cars may be removed without g the main hoist. The coal is then transferred from the ers to the main hoist for elevation to the overhead pocket. is operated by electricity.

FIG. 18 100,000 GAL. STEEL WATER TANKS

rious other types of coaling plants are in successful use, the elevated by belt conveyors or small bucket conveyors, or cranes of various types, with clam shell or similar buckets. operation ranges from two to ten cents per ton, depend- arious factors.

e sand-drying apparatus shown in Fig. 15 is placed opposite station, though frequently a part of the coaling plant is at purpose. One of the most common methods of drying

sand is by coal stoves, which differ considerably in design. The moist sand is delivered from a hopper to a casing surrounding the stove, from which it escapes as it becomes dry. Some of the more modern sand-drying houses use exhaust or high-repssure steam from the power house. After drying, the sand is usually hoisted, by means of compressed air or by some form of conveyor, to a storage bin, from which it is drawn by locomotives when needed. Rotary sand-dryers, in which sand is fed into an inclined tube through which a current of hot air passes, are not commonly used, but could no doubt be used to advantage if a considerable amount of sand were required.

109 The water supply for locomotive use is usually stored in overhead tanks of various capac ities. Fig. 18 shows two steel tanks of 100,000-gal. capacity recently erected. The body of the tanks is unpro-

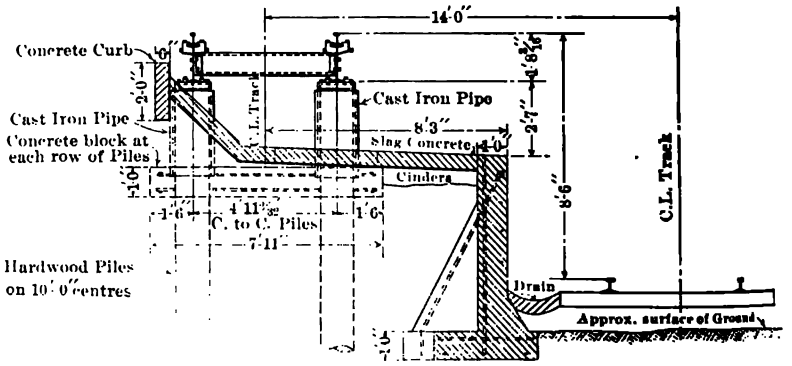


FIG. 19 HALF-SECTION OF ELEVATION OF CINDER PIT

tected from the cold, but the connection between tank and water mains is usually enclosed, as shown, in places where freezing is likely to occur. Standpipes, or water cranes, are so placed that water may be taken without backward movement. Ten-inch cranes are frequently found in modern installations. These will deliver 2000 to 3000 gal. of water per min. under usual conditions.

110 Cinders and clinkers from incoming engines are handled in various ways. An arrangement in common use which has proved very satisfactory is shown in Fig. 19. The contents of the ash pan are dumped on a platform about four feet below the top of the rail, with a slight incline toward a depressed pit into which cars are run for load-

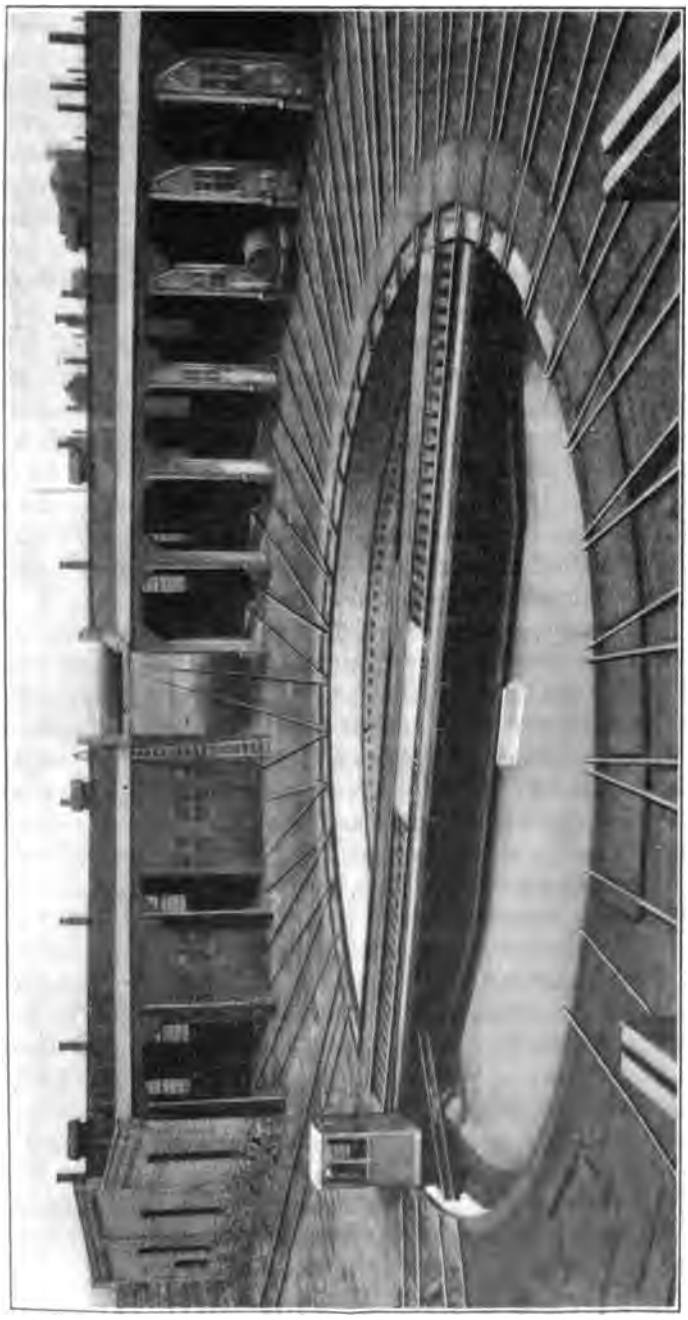


FIG. 20 MOTOR-DRIVEN TURNTABLE

ing. In Fig. 19 the rails are shown supported on wooden upper ends of which are surrounded by cast-iron pipes, with material packed between the pipe and the pile. The use c piers is considered preferable where foundation condition mit. The cinders and clinkers removed from the ash pa down and shoveled into an open coal car standing in the pit. With engine tracks on each side of the pit, several engi accommodated at a time, and the plan affords consideral capacity, so that, with a pit of moderate length, a day force ers is sufficient to take care of the accumulation.

111 In some modern plants the slope from the outer r the refuse from the ash pan into a concrete pit about ei width and depth and filled with water. In this case the removed by means of a traveling gantry crane with clam sl ilar buckets, and delivered to cars standing on the side of th site the engine. In other cases pits are provided betwee in which buckets are placed, and the buckets are lifted o contents deposited in open cars by a gantry or ordinary electric-driven crane with elevated runway.

112 The engine-houses of the United States, usually bei in form, require turntables for the delivery of engines to an house. A common length of table for new installations is 80 a great many shorter tables are still in service, and worki torily where the length of engines is not too great. Tur frequently moved by hand, though a more economical met a considerable number of engines are turned, is by tractor gasolene engines or electric motors. Fig. 20 shows the ap such a tractor to a turntable. The tractor has a heavy ste triangular shape attached to the turntable by means of hi points, the weight being balanced on the single tractor wl ing on the circular rail in the pit. On this frame are m motor, gearing, bearings, shaft and brake, comprising t mechanism. Above the machinery, and entirely covering it, the operator's cab, in which the operating mechanism Electric motors are generally considered preferable where be provided uninterruptedly, and on such installations device is applied to the turntable center. This maintain tion with the feeder line, which is brought underground t of the pit, though, in case the pit is subject to flooding, a collector may be used.

FOLL

THE ENGINE-HOUSE

Fig. 21 shows the plan of an engine-house with thirty 100-ft. and an 80-ft. turntable, on a circle having a maximum provision rty-seven stalls, including inlet and outlet tracks. This plan fire walls separating the house into three rooms of ten stalls The two center stalls are provided with drop pits, by means of driving and truck wheels may be removed and replaced with- cking up the engine. The engines in this house are intended to aded in and backed out.

Reinforced-concrete framing is frequently employed, though ofs are generally of wood and covered with tar and gravel. The exposed iron or steel in roof construction is generally avoided se of the rapid corrosion. The pits are connected at the inner by a drain from which the water escapes through an outlet sewer ying into a large catch basin, or sump, where the sediment is ited.

The pits in this case are recessed for steam-pipes, though the fan blast for heating engine-houses is becoming more and more al, and it is usually found that better results are obtained by se of vitrified tile ducts laid underground and discharged into des of the pits, than by the use of galvanized pipes above ground, generally need frequent renewal. An important advantage of an blast is that it assists in ventilating the house, changing the from eight to thirty minutes, as usually installed and operated.

There are a great variety of smoke jacks in use. The type seems to be coming into favor, is conical in shape and is fre- tly made of wood, lined with sheet asbestos or similar material. e jacks are generally provided with dampers in houses where eat is used, and a space is sometimes left open around the jack sisting in ventilation.

The satisfactory lighting of engine-houses is a difficult problem. gas and electricity are commonly used. Incandescent lamps ry well if kept clean, and have the advantage of portability, ate circuits being frequently provided for extension cords, so light may be carried to any point where it is needed.

Floors of vitrified or paving brick, crowned sufficiently to to the pits, have been found very satisfactory.

Drop pits for the removal of driving and truck wheels are very nient. They are frequently made to span three tracks and of sufficient to take the largest wheel handled. The jacks used

in these pits are generally mounted on carriages, running on rails laid in the pits, and they are usually operated by air or water, though screw jacks are sometimes used. Hydraulic jacks are usually considered preferable to air jacks because of their more positive action. Cranes are generally provided over drop pits.

120 The shop facilities necessary at the engine-house depend upon the distance from large repair shops. Generally speaking, the tool equipment should be sufficient to take care of running repairs, though if the house is located near a repair shop some of the machinery that would otherwise be necessary may be dispensed with. There should also be a tool room, conveniently located with respect to the machine shop and engine-house, in which small tools of all kinds can be conveniently kept and drawn as required. The storehouse should be similarly located and should carry a sufficient amount of material to handle the repairs frequently necessary.

121 There is nothing of particular interest to be said about the power plant of the average engine-house. Boilers, engines and other equipment may be of any type desired. It seems to be the custom to figure on about 10 b.h.p. per stall and, on account of the common use of air tools, a compressor capacity of about 20 cu. ft. of free air per minute per stall is usually provided.

122 Oil houses are generally of fireproof construction, with the oil stored in a separate room from the place of distribution, from which it is drawn or pumped from tanks as required. The oil is usually stored in tanks in the basement, the size and number of the tanks depending upon the amount and variety of oils used. Self-measuring pumps are extensively used in modern installations.

123 Of recent years there has been considerable demand for better and quicker methods of boiler washing, and as a result several systems have been introduced. One of the earlier arrangements consists of an open cistern of perhaps 100,000-gal. capacity, located near the engine house. In this the steam blown off from locomotives is used for heating water to wash out the boiler, and in some cases also for heating fresh water with which to refill it. Recent installations are the National, which is of the open-heater type, in which the steam and water blown off are used for washing out and for heating fresh water; and the Raymer system, which is of the enclosed-heater type and performs similar functions. Blowing-off, washing and filling connections are generally provided between alternate stalls in the engine-house.

124 Locker rooms are generally provided for enginemen, and fitted

with a sufficient number of expanded metal lockers to accommodate their clothing and small tools. These are located in a building near the engine-house office. Lockers are also provided for shop men, and are frequently located inside the engine-house on the walls of the building. The lockers are generally made of sheet steel with openings for ventilation. At points where boarding and lodging houses are not conveniently accessible, bunkhouses are frequently provided for the accommodation of the enginemen. These are usually provided with toilet rooms, shower baths, etc.

THE ENGINE-HOUSE ORGANIZATION

125 The details of handling engines vary greatly on different roads. It seems to be generally customary, however, to have the engineer relieved at the coaling station by a hostler, though at some plants inspection pits are encountered before the engine reaches the coaling station, and the engineer is relieved at those points. In some cases also the cinder pits are reached before the coaling station, though it is generally considered better practice to have the cinder pits next to the engine-house, so that if the fire is dumped the engine will have but a short distance to travel and encounter but little delay before reaching the house. The hostler, however, takes coal, water and sand, and moves the engine to the turntable and thence across to the house.

126 The engineer makes out a statement on arrival, commonly called a "work report," on which he indicates the condition of the engine and any work which he may know to be necessary. The engine usually receives an independent inspection, however, and notes are made of any work required which has escaped the attention of the engineer. The foreman, or his assistant, distributes the work and is responsible for its performance.

127 Especially at large terminals, engines are frequently stored outside and do not enter the house except for boiler washing or heavy work of some kind. Switch engines, especially those that work night and day, are usually so handled.

128 The organization varies with the requirements, but the engine-house and its plant are generally in charge of a foreman who has general supervision over the inside and outside operation. He reports to the master mechanic or general foreman, and attends to locomotive repairs and service including the assignment of enginemen to their runs. He usually has an assistant who attends to the dis-

tribution of work, including the supervision over such foremen of the various classes of work as may be required. Efforts are usually made to keep the night work as low as is consistent with the prompt handling of engines coming in for service or repairs.

129 The cost of service varies greatly at different points. Most roads do the greater part of their work at the more centrally located engine-houses and comparatively little at outside points. This naturally causes a considerable difference in the cost of service, but in addition to this, various local conditions, such as the quality of boiler water available, the condition of track, the general condition of the power, and the available help and wage scales, have a considerable effect upon the cost of service. On one road with which the writer is familiar, the cost of service per locomotive varies from $0.50 or even less, at outside points, to about $3 at one or two important central points where a considerable amount of heavy work is done. The average cost by months for all engines housed during the eight months from July 1909 to February 1910, ranged from $1.50 to $1.73. These figures include service only. The average cost per engine for the eight months is shown in the table.

AVERAGE ITEMIZED COST OF ENGINE-HOUSE SERVICE PER MONTH PER ENGINE

PASSENGER ENGINES

Hostling	$0.12
Calling	0.05
Wiping	0.41
Cleaning	0.26
Headlight cleaning	0.07
Boiler washing	0.87
Tank washing	0.11
Flue cleaning	0.10
Inspecting	0.15
Firing-up	0.16
Engine-house laborers	0.16
Turning table	0.04
Clinkering	0.24
Supply men	0.13
Coaling engines	0.10
Sanding engines	0.11
Watching engines	0.18

130 The cost of service rendered freight engines on the same road during the year ended June 30, 1909, was 8.4 cents per thousand ton-miles.

No. 1290 *e*

AMERICAN LOCOMOTIVE TERMINALS

By William Forsyth, Chicago

Member of the Society

l The most interesting example of American engine-house prac- s that in the classification yards of the Pennsylvania Railroad at Altoona, Pa. Here the traffic from three divisions of the road ncentrated, classified and despatched. The freight tonnage ng through this terminal is claimed to be the largest handled y single system of freight yards in the world. The total capacity e yards is 10,500 cars.

? The eastbound traffic is composed largely of loaded coal and ars, and the number of cars handled per month in this direction ded, 61,308; empty, 1306; total, 62,614. The westbound move- is composed largely of empty cars, with a total of 62,877 cars nonth. In 1906 an average of 90 trains per day was received the Pittsburg division and 60 from the Middle division, and the ment in one direction reached as high as one train every ten es for six hours. During the month of November 1909, the e movement at this engine-house was as follows:

ge number of locomotives despatched east and west in 4 hours	243
mum number despatched in 24 hours	290
mum number despatched in one hour including switch ngines	40

The trains are operated by consolidation locomotives, and on nt of the grades on the eastern slope of the Allegheny moun- westbound trains require three engines, two in front and one as ner. Eastbound, the line follows a comparatively light gradient the Juniata river, and here large trains can be handled by one lidation engine. There are 35 switch engines, requiring 70 e crews for day and night operation. During the month of

ented at the meeting of The American Society of Mechanical eers with The Institution of Mechanical Engineers, Birmingham, nd, July 1910.

November 1905, there were handled over the ashpit a tota engines. The number of men employed in the yards is 18 number of enginemen employed during the month averaged the number of men employed about the engine-house, s coal wharf and on the motive power roll was 700.

134 Near the center of the length of the terminal (Fig. 22) a large engine-house, with ashpits, coal wharf, sand supply sized machine shop, storehouse and office, with bunk roo head; also a power house, a fan house for heating, an oil h a toilet and locker house.

THE ENGINE-HOUSE

135 The engine-house is in diameter and cross-section t structure ever erected for this purpose. It has an exterior of 395 ft. and a turntable of 100 ft. There are 52 stalls 9(The main portion of the house is 65 ft. wide and 30 ft. high outer circle there is a lean-to 25 ft. wide and 18 ft. high. Th head in toward this lean-to and the smokejack is located the main columns at the outer portion of the main build main portion of the house was made 30 ft. high to acc a traveling crane, but columns for supporting the crane been erected, as jib cranes secured to the main columns w more desirable. A cross-section of this engine-house is Fig. 23.

136 The turntable is operated by an electric motor. four drop tables, also operated by electric motors, two of driving-wheels, one large table for all wheels except the engi and another for pony truck wheels.

137 The coal wharf is a large structure arranged with approach having a grade of 3.88 per cent. The coal is dro hopper cars directly into bins and no cover is provided fo as they are emptied entirely by gravity and no men are in the unloading. The storage structure is 32 ft. wide a long. A special gate and hood are used for regulating t coal from the pockets to the tender. A steel gate drops floor of the pocket and is operated by a compressed-air

138 At one end of the coal wharf is a sand house, wh dried in large stoves and descends through a grating to a from which it is elevated by compressed air to the sand head, and flows by gravity to the engines.

FOLDER No. 10

39 Near the approach to the coal wharf are four ashpits, each ft. long, two on each side of the wharf incline. Each pair is rated by an overhead 5-ton electric crane which spans four tracks, of them over the ashpits for ash cars. Ashes are dumped from engines into steel buckets which run on wheels on a track in the

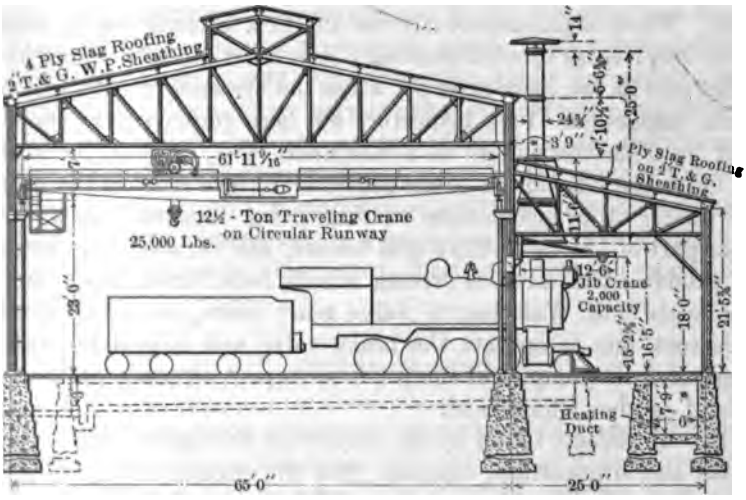


FIG. 23 CROSS-SECTION OF ENGINE-HOUSE AT EAST ALTOONA, PA.

pit. These buckets are elevated by the crane and transferred the ash car, where they are dumped. Beyond the ashpits at the reme end of the coal wharf are inspection pits, 80 ft. long and t. deep, and connected by an underground passage extending ler the coal wharf track.

ENGINE-HOUSE ORGANIZATION

140 The work performed in an engine-house includes almos erything in connection with locomotive repairs that does not quire the locomotive to be sent to the general repair shop. No empt will be made to itemize these repairs. The work which ust invariably be performed periodically consists of boiler testing ery six months; boiler washing, from once a week to once a month necessity arises; staybolt testing each week; examination of oke-box, draft arrangements and ash pans, each week; testing am and air gages each month; washing tenders each month;

gaging height of pilots each week; gaging tank water scoops e trip; testing air brakes each trip; draining main reservoirs e week.

MANNER OF REPORTING AND PERFORMING DAILY WORK

141 When a locomotive arrives the first information the or zation receives as to work necessary is in the engineer's report w he delivers at the inspection pit when the locomotive is turned to the inspectors. Five inspectors are here employed, as the must be done thoroughly in a minimum time, so that the h can move the locomotive to the ashpit and make room in the in tion pit for other locomotives waiting. One inspector examine under-part of the locomotive and tender; one on each side ins the outside parts, such as driving wheels, rods, steam chests, g crossheads and Walschaerts valve gear; there are two air- inspectors, one to operate the brake valve and inspect the fi in cab and air pump, and the other to inspect all other parts o air and sanding equipment.

142 All defects found by the inspectors are entered upon n blanks and transmitted, together with the engineer's report, t gang leader in charge at the inspection pit, who decides whet is necessary to send the engine to the house or whether the r are so slight that they can be made on the outside repair pits in nection with the outbound storage tracks. His decision is m upon the report, and upon the steam chest of the locomotive the reports are forwarded to the work distributor's office by pneu tube in 45 seconds. This saving in time over the 10 minutes narily required by messenger is a decided advantage to the distributor, as he is able to assign the work to various gang le and have the necessary material ordered, before the locon arrives in the house or on the engine track.

143 While the inspectors are at work the lamps and torch filled and trimmed by two lamp fillers. There is no further ne for the engine-house force to open the tool boxes, which are l by the engineer, and the keys, together with his time card, del to the engine despatcher at the foreman's office. The en is then relieved of all responsibility and of the care of the lo tive.

144 The engine moves from the inspection pit to the ashpit, the firebox, ash pan and smoke box are cleaned. It then mo

he coal wharf, where the tender is filled with coal; and a little farther n reaches the sand house, where it receives a supply of sand and ater. It then moves into the engine-house or to the outbound torage tracks, as necessity requires. If it goes to the engine-house he track number and the time of arrival are reported by the turn-able motorman by telephone to the work distributor, who by this ime has the work which was reported by the inspector and engineer ubdivided and assigned to various gangs. After completing the vork these gangs report the locomotive ready for service to the ngine-house office, where arrangement is made for the movement f the locomotive to the storage siding to await assignment to train. If the locomotive does not go to the engine-house it is noved directly from the sand house to the storage siding, and the ecessary work is assigned to a gang located on the storage tracks o make light repairs, after which the locomotive is reported ready or service.

ENGINE TRACING

145 At East Altoona there are sometimes as many as 200 loco-notives within the engine-house jurisdiction and it was found neces-ary to inaugurate some efficient method of locating them exactly t all times, so that men sent to make repairs will have no ifficulty in finding any particular locomotive required. This is ccomplished by telephone. Each time a locomotive moves to nother locality the engine tracer in the foreman's office is advised s to where it came from and where it has been delivered, giving the umber, the location on the track and the time in each case. When raffic at East Altoona is normal the engine-house must deliver eady for service one locomotive every five minutes during the whole 4 hours of the day, as the engines for three divisions are here con-entrated. It is vitally important that everything should run in bsolute harmony as any interruption in this rapid flow would quickly esult in a congestion on the road.

ENGINE DESPATCHING

146 After the engine tracer has been advised that a locomotive s placed on the storage track for service, he informs the engine espatcher, to whom the crew callers report. The engine despatcher s also in touch with the yardmaster and is the middleman between

the engine-house foreman and the yardmaster. As soon as the yardmaster receives information that he needs a locomotive and crew for a certain train of a given class at a certain time, he advises the despatcher, who immediately calls out a crew, and when they arrive assigns to them the locomotive selected, which is standing on the outbound storage track. A telephone system has been installed whereby all crews may be called. The houses of the enginemen have been equipped with telephones connected with the engine-house office, an arrangement which dispenses with messengers and enables the crews to be called very promptly.

147 The fireman usually arrives first, and after receiving his time card and keys he takes charge of the locomotive, relieving the engine watcher of any further responsibility, and immediately prepares a fire for road work. The engineer, upon arrival, after receiving his time card at the engine-house office and inspecting the bulletin board to read any new orders, goes to the locomotive and oils the machinery, and then waits until he is given the proper signal to move out of the storage yard. The crews are usually called in sufficient time to prepare the locomotive properly for road work prior to leaving the storage track.

ORGANIZATION OF STAFF

148 For the operation of this locomotive terminal an elaborate organization has been worked out, based upon the principle that none but the heads of sub-departments shall report to or receive instructions from the foreman, his assistant or the work distributor. The responsibility of supplying material and the supervision of the workmen are placed directly upon these gang leaders, who are foremen of their respective gangs. Certain questions of discipline must be handled by the foreman personally, but questions relating to rates of pay, transfers, discipline, etc., ought to originate with the gang leaders, and their duties not be confined to giving out work to the men after the distributor has assigned it. This results in successful operation, but it also gives some dignity to the position of gang leader, and at the same time relieves the foreman of petty details.

149 The foreman of a large engine-house should not be an ordinary shop man, but should have some outlook over and interest in the operating department. He should be a good disciplinarian, commanding the respect of his men, should display clear judgment and

conclusions quickly. He should be a good all-round organizer apable of taking care of business promptly during rush hours. ould know how to make brief and intelligent reports and possess anical ability. He should be broad-minded enough to recog- hat there is a commercial side to transportation, and should overburdened with office work. His assistants should possess ent ability to decide what work may be slighted or not done and a locomotive still be safe to make one or more round trips.

The engine-house foreman receives from the division master- anic instructions pertaining to such matters as the number n required, rates of pay, discipline, maintenance of his entire and standards. He receives from the division superintendent ctions relating to crews and despatching of locomotives, and s out such discipline of the engine crews as may be imposed e division superintendent through the road foreman of engines. ust coöperate with the road foreman of engines concerning the tion of power and its performance on the road, and the amount l and oil consumed. He must carry out orders issued by the foreman of engines concerning the assignment of locomotives rews. At East Altoona the engine-house operation is a con- us one throughout the day and night, and the night force is ically the same as the day force.

Reporting directly to the engine-house foreman are the *assis- ay foreman and assistant night foreman.* Reporting to assistant en for office work are the *first clerk*, who takes all the foreman's he assistant foremen's dictation, and the *second clerk*, who has e of all messengers and ordinary clerks who may be engaged nputing the time and earnings of the men and in getting together e information required by the master mechanic's shop clerk or properly keeping the records. Next in order is the *engine tcher*, to whom report the *engine tracer*, the *callers* and the who keep the records of engineers and firemen and of locomo- arriving and departing. The engine despatcher marks up rew board, issues time cards to engine crews going out, and ts and approves them upon their return.

Next in order reporting to the assistant foreman are the various *leaders*. First is the gang leader in charge of the machine shop. vork of his men is confined to machine and vise work, and they ot called upon to leave the machine shop and make repairs in comotive shop or storage yard except in cases of emergency. work is chiefly preparing and fitting the repair parts which

the engine-house employees apply to the locomotives. The gang leader in charge of the blacksmith shop has charge of all smiths and helpers, as well as the forces of flue welders and laborers in the engine-house engaged in piecing flues and preparing them for locomotive boilers. The gang leader of the power plant has full charge of stationary engineers and firemen, electricians and wiremen. Another gang leader has charge of the ordinary helpers and sweepers in the engine-house, who keep the shop property clean.

153 The foreman in charge of all employees actually handling locomotives, from the time they arrive at the terminal until they are turned out, also of all workmen engaged in the engine house or storage yard, is called the *work distributor*. Clerks reporting to his two *assistants* receive the engineers' and inspectors' work reports and copy the work required on slips of paper numbered consecutively and properly dated. These slips are then delivered to the gang leaders of the men who perform the work.

154 The men composing the gangs working on a piece-work basis are divided into pools of three or four men, with leaders. The pool *leaders* are under the direction of gang leaders. When the earnings of three or four workmen are pooled it is found that each man is determined that the others should perform their fair share of work, and in case one man fails to do this the remainder insist that the lazy or careless workman be taken out of their pool.

155 The gang leaders at the inspection pits are in charge of *inspectors, lamp fitters and engine preparers*, who handle the locomotives between the inspection and ashpits.

156 There are three *assistant gang leaders* in charge of the *engine preparers*. Assistant No. 1 has charge of all work in cleaning fires and placing the locomotives in the engine house or storage yard and of *the ashpit men and crane operators* who load cinders. Assistant No. 2 has charge of the *coal gagers and sand house men, turntable operators* and men engaged in handling locomotives from the engine house to the storage yard. Assistant No. 3 has charge of the men handling locomotives in the storage yard and despatching them when ordered for service, including *engine watchers, switchmen and engine timers*.

157 Next reporting to the work distributor is the *gang leader of boiler washers*, whose men wash out the tenders, blow out, wash, fill and fire all boilers, and watch locomotives until they are removed from the engine house. Next is the *gang leader of staybolt inspectors*, whose men test staybolts and examine fireboxes and tubes. There

s a *gang leader of boiler makers*, engaged in renewing tubes and stay-
olts, patching, testing and calking tubes, and general boiler work.
A *gang leader of engine cleaners* has charge of men cleaning locomo-
ives and tenders. There is a regular schedule for doing this work,
nd it is so arranged that the work is performed when the locomo-
ives are receiving staybolt repairs or boiler washing. A *gang leader*
of spongers is in charge of packing journal boxes and other work
elating to lubrication. In the engine-house there is a *gang leader*
of machinists, who are engaged in setting valves, renewing packing
nd all other general machinist work on the locomotive proper.
The *gang leader of tank repairs* is in charge of repairs to tenders,
rames, tanks and couplers, of renewing truck wheels, and other
ender repairs. The *gang leader of air-brake repair men* keeps in
rder the air brakes and sanding equipment.

158 The gang leaders of men on piece work should have not more
han ten or twelve men under them, with the exception of the gang
n boiler work, which may require from one to four days to complete.

POOLING LOCOMOTIVES

159 Improved engine-house facilities, more system and better
rganization are favorable to the pooling of locomotives, and this
ractice has become more general for freight engines in the United
tates. As recently as in 1905 the reports on pooling presented
t the International Railway Congress indicated that pooling was
ot used on the majority of railways in the United States under
ormal conditions of traffic. The large increase in traffic in propor-
ion to the number of locomotives in 1906 and subsequent years has
ompelled most of the roads to resort to the pooling of freight engines
nd the double-crewing of passenger engines, and these methods are
ow well established on the majority of American railways. By
mproved methods the operations of cooling down, washing, and
illing with hot water may be performed in less than two hours with-
ut injury to firebox and tubes, and this alone has contributed in a
arge measure to the success of pooling. The reduction in boiler
ressure from 225 lb. to 160 and 180 lb. has also reduced the number
f boiler failures and permitted the more continuous use of locomo-
ives which results from the pooling system.

160 The amount of work which the engineers and firemen do at
he engine-houses is now so small that it is almost confined to lubri-
ation of machinery and inspection of tools and supplies on engines,

and no dependence is placed on them for repair work. The engineer is required to report any defects or needed repairs which he observes while running the locomotive or by casual inspection on the outside. The machinery underneath is inspected by men regularly employed for that purpose, and inspection pits in the tracks approaching the engine house are now regarded as an essential of a modern locomotive terminal. With the changes in practice above indicated, the pooling of freight engines is rendered more successful and satisfactory and its effect on the cost of locomotive repairs is not so pronounced as formerly.

161 On some railways where shop facilities are limited, locomotives are required to make a large mileage before they go in for general repairs. The principal items which send engines frequently to the shop are worn tires, defective tubes, and, perhaps, worn driving boxes. At some engine-houses all these repairs are made, the worn tires being replaced by new ones or by others which have been turned at the shop. In this way such machinery as rods, crossheads, guides and link motion, is kept in service, so that passenger locomotives make as high as 127,000 miles, and freight locomotives, 100,000 miles between general repairs, one passenger locomotive making 256,000 miles between shoppings. Passenger locomotives average 120,000 miles and freight locomotives, 95,000 miles.

162 On the Chicago, Burlington & Quincy for the last six months of 1909, pooled freight engines made on one division as high as 4167 miles per month and 110 engines on three divisions averaged 3777 miles per month. On other roads passenger engines double-crewed make an average of 6500 to 7500 miles per month, one road reporting for engines in express service 418 miles per day and 12,780 miles per month.

No. 1290*f*

HANDLING ENGINES

By H. H. Vaughan, Montreal, Can.
Member of the Society

The desirability of pooling engines in place of operating by regularly assigned crews depends, in the writer's opinion, on ıer the engines are engaged in passenger or freight service, and ı latter case, on the conditions which exist.

PASSENGER SERVICE

Where traffic conditions admit of the engine making greater ge than can properly be run by one crew, two crews assigned to ıgine, or three crews to two engines, will enable the engine to as great a mileage as is desirable. On account of the compara- short time occupied from terminal to terminal, the crews can y make a round trip without holding the engine longer than is ed to handle it and prepare it for the return trip or to await its By using more than one crew to the engine, it is theoretically ble on its return just as soon as though it were pooled. In prac nless pooling is carried to the extent of sending out any engine y train, certain engines are regularly used on certain trains or ȝ of trains, and it is comparatively easy to arrange the crews ıgines so that a reasonable time may be allowed for repairs and ıple service be obtained from the engine. When working with ed crews it is of course usual to employ some extra passenger o take the place of the regular men, who are also available ȝ an extra trip is required from an engine on account of specials ra sections of regular trains. Where regular scheduled trains to be provided for, this system is as flexible and convenient

ented at the meeting of The American Society of Mechanical eers with The Institution of Mechanical Engineers, Birming- England, July 1910.

as pooling and has the additional advantage in passenger service that the men run certain trains regularly, and will consequently give better service than when handling a number of trains indiscriminately.

164 Pooling in passenger service probably does not require much discussion. The system is not in extensive use and will presumably have few advocates. The writer would, however, state as a result of his experience with both pooled and assigned engines in passenger service, that he is most strongly opposed to pooling in this service and considers that far better results can be obtained from assigned crews.

FREIGHT SERVICE

165 Here conditions are very different. The time is slow and a long time is occupied from terminal to terminal, so that crews may require a full allowance of rest on arrival, or may even have to be relieved on the road. Few, if any, of the trains run at regular hours, and in place of following a defined schedule, the demand for engines varies with the traffic. When business is heavy, engines are wanted as soon as they are repaired and ready for service, making it difficult, if not impossible, to select the engines in any particular order. By pooling, such difficulties may be more easily met, especially at large terminals. When engines are assigned the practice usually required by the agreement with the men is that engines shall be prepared and despatched in the order in which they arrive, but if the engine is ready its use may be retarded by the time required by the crew for rest. In pooling, both these objectionable conditions vanish. An engine may be turned at once if fit for service and thus rendered immediately available, and the movement of the men being entirely independent of that of the engines, the detention of engines at a terminal can be regulated by simply increasing or decreasing the number in the pool.

166 Under such conditions, if pooling is not carried on in name, it will be in fact, simply because business can not be handled unless engines are used without reference to the order of their arrival. Granted therefore that pooling is advantageous under these conditions, it should be done properly. All the features necessary to a successful pooling system must be employed, such as thorough terminal inspection independent of the engine crews, and arrangements for handling tools and engine supplies, and caring for headlights, oil cups, etc. If pooling is resorted to when business is especially heavy, or

when traffic is disturbed by storms or by other causes, without proper arrangements being made, the results are most objectionable. Under these circumstances, the condition of the power will depreciate rapidly and the service rendered will be exceedingly inefficient. The maxim is frequently stated, "If you pool, pool," and its wisdom has been demonstrated by experience. The real question about pooling is therefore whether there are conditions under which it is preferable to adopt the alternative practice, that of running engines with assigned crews. This depends on the results obtained from the two systems, which are in the writer's experience as follows:

167 *Mileage.* It is possible to obtain a somewhat greater average mileage per engine under the pooling system, but the increase does not exceed ten per cent when traffic is being handled smoothly and without excessive congestion and delays.

168 *Repairs.* When running successfully under the assigned engine system, repairs are less than when similar conditions exist with pooled engines. A man running an engine regularly keeps up the smaller details and knows what work is required at once, and what must be looked after in due time. His inspection reports are more reliable than those of a man who has had an engine for one trip only. As he has to run the engine next trip as well, he will handle it with greater care and avoid any action that will cause him trouble in the future. Men who have been accustomed to running pooled engines will not do all this at once, but they most certainly will if assigned to an engine for any length of time, and the difference is noticeable in engine-houses where some engines are assigned and some are pooled.

169 Engines are sometimes taken care of by the headquarter station system, the work required to maintain the engine in proper condition being done at the terminal designated as the home station, while at the other terminal the only work done is that necessary for the return trip. With this arrangement, even with pooled engines, the same crew will, if possible, make the round trip; but when they are changed, practically as much work is required at the away station as at the home station. The result is a considerable increase in the cost of repairs, for there is not as a rule very much difference in the cost at the home station.

170 When the assigned engine system proves inadequate for traffic demands, the results change. Men will endeavor to book enough work against the engine to hold it until they have rested, and on the other hand engines are liable to be wanted before repairs that are actually required are completed. Under these conditions engines may be bet-

ter and more cheaply maintained when pooled; but under normal conditions the writer's experience would show that with assigned crews the cost of running repairs may be reduced five to ten per cent and better mileage obtained from the engines between shoppings.

171 *Fuel.* It is almost impossible to determine the fuel consumed by an engine on an individual trip, and consequently difficult when pooling to keep any record of the amount of coal used by different men. A record may be kept by engines, but it is then impossible to locate the responsibility for any excessive consumption. The practical result is that on pooled engines, individual fuel records are of comparatively little use. With assigned engines, while trip records may not be individually accurate, the average of several consecutive trips soon becomes so, as the variation of the amount of coal left on the tender, while important on one, is of comparatively small importance on a number of trips. There is no doubt in the writer's mind that individual coal records, whether by trip or by period, are an important factor in obtaining economical results in fuel consumption, both from men and from engines, and he ascribes the good results that have been obtained on the Canadian Pacific Railway largely to the careful way in which the records have been watched.

172 Apart from the records, the familiarity of the men with the engines has an important bearing on fuel consumption. Most engines vary slightly in the way they burn the coal, in the nature and intensity of the draft, and in the best position for the throttle and reversing lever. Crews knowing an engine thoroughly learn about these peculiarities, while they do not when running a different engine each trip. One crew will obtain from an engine results that are impossible for another crew, and thus the result with assigned crews is a tendency to higher efficiency than when every engine has to be drafted and adapted to do the work with the poorest crew on the division. It is only necessary to watch the difference in the way an engine is handled by a regular crew and by a pooled crew, to realize the advantage of the former, and important results have been clearly shown with the same men and engines, on divisions where the two systems have been in effect.

173 *Service.* The remarks that have been made in connection with repairs and fuel apply with almost equal force to the class of service obtained from the engines, with reference to failures, breakdowns and ability to make the time required. A crew that knows the engine will get more out of it than one that does not. They will notice any difference in its working and will take more interest in getting

ıy defect rectified. They will keep their equipment in better condi-
on and will pay more attention to bearings which show signs of heat-
ıg, etc. All these conditions lead to better and more efficient service.

174 *Engine-House Expenses.* Inspection, the care of tools, the fill-
ıg of lubricators, headlights and cab lamps, are commonly looked
fter on assigned engines by the crews. When engines are pooled this
'ork has to be done by the engine-house force. At a large terminal
ıis expense is not large, but when the number of engines handled is
nall, it is difficult to arrange the duties of the men doing this work
› prevent its becoming a serious item. Conditions vary on different
›ads in this respect, but the fact remains that this work is not in any
'ay burdensome to men having a regular engine, while it is burden-
›me if they are required to prepare a different engine each trip, and
›nsequently they object to it very strongly. In the majority of cases
ıis work constitutes an additional charge on engines that are pooled.

CONCLUSION

175 In conclusion, the writer considers that in passenger service
ooling is objectionable under any conditions and should be avoided
possible.

176 In freight service, pooling is advisable if conditions are such that
ngines cannot be run with assigned crews, and probably on divisions
'here business is so heavy that sixty engines per day or over are des-
atched from the terminal; but the writer's experience is that where
ssigned crews can be used on engines, the cost of repairs, the amount
f fuel consumed, and the class of service obtained, will all be more
atisfactory.

177 He therefore regards pooling as a practice that may be neces-
ıary under certain conditions, but that is certainly not desirable if the
ılternative system can be satisfactorily carried out.

No. 1290*d*

CUSSION ON LOCOMOTIVE HANDLING AT TERMINALS

EORGE HUGHES,[1] in opening the discussion, said that in Fig. 5 Paget gave a drawing of a through-straight shed. On the e, however, it appeared to him that greater prominence was n to the round sheds, because more drawings were given of ı, and the members possibly took more notice of full-page ings, although the general practice in this country was the ght shed. The form of shed adopted by the Lancashire & shire Railway was a straight shed with a dead end, that is, it not a through shed, and it was their general experience that no t difficulties were encountered. It was necessary for the shedmen xercise care in shedding the engines, and there were generally n or eight engines on one road. Certain roads were delegated ashing out, and as a rule, it was known which engines required iring, and consequently with a little common sense they were to work the sheds economically. The feature of the round shed that it was possible to get at any individual engine, and move ı and out quite easily, so long as the turntable was in good order. vas readily conceivable in that case, that if an engineer put all eggs into one basket he took extraordinary care of that basket. wever, in the case of moving a dead engine, say, from an ordinary he sheer-leg road, such dead engine could only be moved by a ıber of men with pinch-bars, unless two live engines and two addi- ıal clear roads were available.

le agreed with what Mr. Paget said on the question of washing , that it was highly desirable to introduce a hot-water apparatus changing and also for washing out. The engineer obtained his ırn from the saving in repairs to boilers; and for a railway com- y spending £70,000 or £80,000 on boiler renewals or repairs annum, it was quite conceivable that it was fairly easy to get a

M. I. M. E., Chief Mech. Engr., Lancashire & Yorkshire Ry., Hor- ı, Eng.

return there. His company had given considerable thought to the question and proposed, when extensive alterations were being carried out in certain sheds, to install such an apparatus.

Mr. Paget had laid considerable emphasis on engine-shed stores, saying that if the stock of stores was kept down, the standing charges would thereby be reduced. It would be of interest if Mr. Paget would be good enough to say what value of stores he held in stock at the running sheds per engine in steam. For the information of those present, he might state that on the Lancashire & Yorkshire Railway the figure was £8 5*s*. He did not know if that was a high or low figure; he was rather inclined to think it was a low figure. He would very much like to know what American practice was in that respect. As Mr. Paget had pointed out, they had been able to arrive at the state of things described in the paper by having six traveling vans, three of which were always at headquarters, and three between headquarters and the various sheds. If they got a demand at Horwich at 5.30 p.m. for a big end or for a repaired injector, or whatever might be wished, it could be delivered at Goole, 84½ miles away, by 8.30 in the morning. They also had a central stores for running repairs materials which considerably assisted in the matter, and as a result, they had been able to keep down the percentage of engines waiting for materials from headquarters to a very great extent.

A great deal of water softening was done by different railways. His company had several plants, and for a number of years had used a boiler composition which consisted chiefly of sodium carbonate and a small percentage of caustic soda, which had been fairly successful in keeping the scale soft. On the Lancashire & Yorkshire Railway system there was a very large percentage of hard water, and also water containing a large percentage of solids in solution, and consequently several proprietary articles had been tried during the last few months with considerable success.

So far as he remembered, nothing was said about engine cleaning either in Mr. Paget's paper or in the American papers. There was one great feature in English running-shed practice, as distinguished from American and continental practice, to which he wished to call attention. English railway companies spent a considerable sum of money on cleaning, a three-fold result being obtained. First of all they believed it was a good advertisement; secondly, they thought it had a considerable moral effect upon the enginemen, and consequently upon the repairs to the engines; and, thirdly, it was the training ground for the young men who eventually became firemen and

drivers, so that in the case of emergency, of heavy excursion traffic or a heavy glut of goods traffic, there were always a number of men to fall back upon to take the place of firemen, the senior firemen taking the place of drivers, so overcoming what he believed was a difficulty in the States. If that was not the case, he hoped some of their American friends would correct him.

He had compared his company's practice in regard to the number of engines waiting for repairs, and being washed out; and it was a curious coincidence that it came out practically the same as Mr. Paget's. He would like some further information on the proportion of failures, a question on which very little had been said—he did not know why. If some of his friends knew how bad his failures were, it might encourage them to say how good theirs were, and it might, therefore, be useful if he stated that, on the average, he had two engine failures per day, that is, engines unable to continue their journey, and there were just over 1000 engines in steam per day. However, if those failures were included which did not cause any delay to traffic, the number would drop down to one half at once. For the month of June the number of failures to passenger trains where a delay of ten minutes and upwards was caused, was sixteen, and the goods trains nine. The chief causes of the failures were leaky tubes, and occasionally burst tubes; about fourteen per cent of the failures were due to leaky tubes, and five per cent to burst tubes; in addition to which, hot axles, and so on, were responsible for a certain proportion of the failures. Another thing which engineers in this country had to contend with was the extraordinary care which had to be taken to keep the men's hours within the limit of twelve, to do which required a considerable amount of organization.

In Fig. 20 Mr. Clark showed a turntable fitted with a motor-driven pony truck, and it also appeared that American turntables were about one hundred feet in diameter. He wished to say quite candidly that he envied American engineers in that respect. He mentioned the question because his company had recently introduced 60 and 65-ft. turntables, but it already possessed many 55-ft. turntables in excellent order, comparatively speaking, and consequently it would not be a commercial proposition to scrap them simply because the engines were getting very heavy at the smoke-box end. A small 3-h.p. pony truck had recently been introduced for operating the turntables, and their life had thereby been very considerably prolonged. He had been much interested in the general plan of the East Altoona shed (Fig. 22). He remem-

bered very vividly how impressed he was with that shed and yard, and also with what appeared to him an extraordinary operation going on when he visited that station some five years ago. It was a Sunday morning, and a freight engine had just come in with the center driving tire very slack. He found that a gas ring had been put round for the purpose of expanding the tire, and pieces of thin sheet steel were being pushed in between the rim and the tire. The tire was then allowed to cool down, and within a reasonable time the engine went out again on the road. The fire was never drawn out of the fire-box, and the engine was in use again the same afternoon. That was all very well in its way, but he was not quite sure whether he dared to do the same thing. On the Lancashire & Yorkshire Railway, when such a repair was needed to an engine the wheel would be taken out and properly attended to. From the American point of view, no doubt it was good practice; it kept the engines away from the repair shops for a longer time, and so on. In this country for some years the lodging-house system or enginemen's barracks, had been introduced for the drivers, firemen and guards.

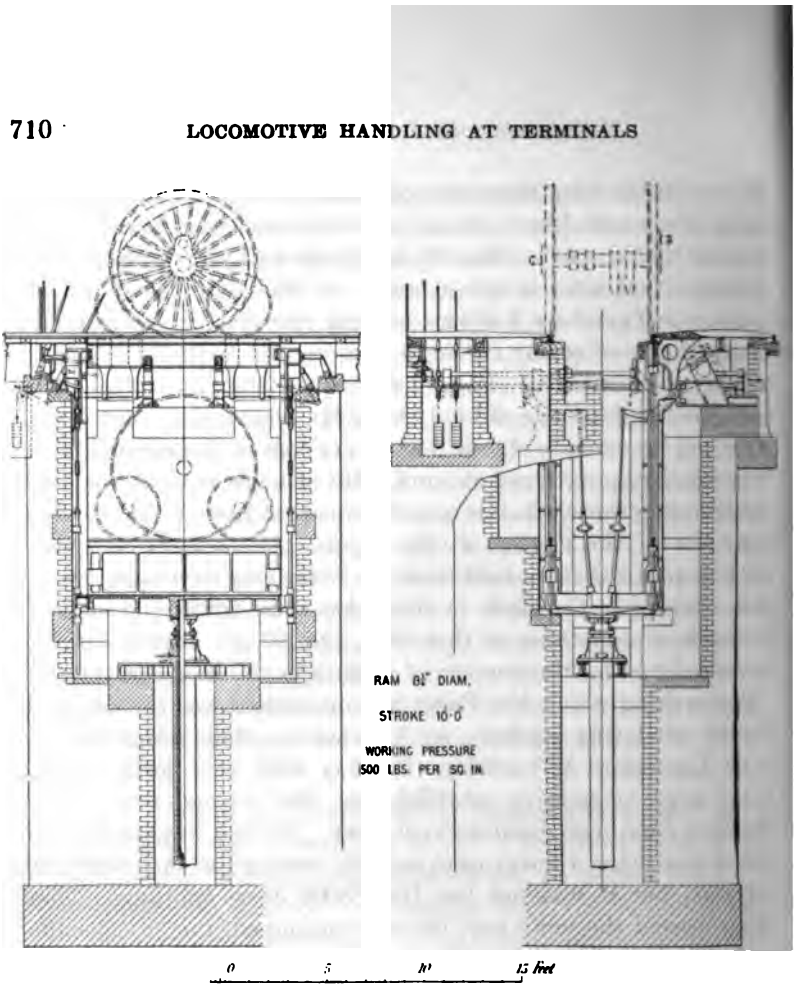
JOHN A. F. ASPINALL,[1] before calling on the next speaker, desired to make a few remarks with the object of tempting some of their American friends to make some observations on points which compared with English practice. He noticed that both in America and in England it was the practice of a great many of the railway companies when an engine had to be lifted at a running shed, either because it had a hot box, or something else was wrong, to put it under a sheer legs and lift the engine up, take a pair of wheels out, and examine the tire or the axle-box, as the case might be. He ventured to think there was a much better way than that of doing the work, one which was in use in this country, and which it seemed to him was also better engineering. He suggested that a hydraulic wheel drop should be placed in the engine sheds, so constructed that the pair of driving-wheels could be placed over it and the keeps slacked out, as soon as the engine came in; the wheels could then be dropped down below the engine; the axle-box could be examined, fitted up again, and put right in the course of an hour or two; the wheels could be pushed up into their place, and the engine could go out again without any trouble. He thought that was better engineering, because it

[1] Pres. I. Mech. E., Genl. Mgr., Lancashire & Yorkshire Ry., Hunt's Bank, Manchester, Eng

far better to drop three tons of wheels than to lift thirty tons of ines. He would like to know what the modern American prac- was in that respect. Figs. 24 and 25 showed photographs of the el drops that were in use at most of the engine sheds on the ıcashire & Yorkshire Railway, so that the members might have opportunity of seeing the form of apparatus actually in use.

)ne remark which Mr. Paget had made might, he thought, lead nisapprehension. He did not think Mr. Paget quite meant what said, but he actually stated that 25 per cent of the engines on the dland Railway were not at work. He believed it would be found ,t the usual practice in this country was that there would be about per cent of the engines at the shops. He thought Mr. Paget ıst have meant that the balance of the 25 per cent were being washed t or detained in the sheds in order that some trivial job might be formed, or something of that kind, but 10 per cent would be a sonable figure for the number of engines in the shops at one time.

Another thing which Mr. Paget had mentioned was the use of the)llerith tabulating machine, an American machine which was used the Lancashire & Yorkshire Railway with very great success. any large locomotive establishment the drivers' returns were :eived in enormous numbers every day. He had forgotten for the)ment how many returns were actually received in their own office ery day, but it was not less than 3000 every morning. Those turns showed the miles run, the coal consumed, the oil consumed, e time occupied, etc. All those figures had to be tabulated, so at statistical returns of the work done could be properly recorded.) write all that out would mean an enormous amount of clerical bor. He did not wish to go in great detail into the subject; he erely desired to draw the attention of the members to the particular rm of machine used, because it was so good for tabulating purposes,)t only for the particular purpose to which he had referred, but for aling with all sorts of engineering figures. The process was roughly follows: A document came in which was covered with figures.)rresponding cards were printed, which had places on them for ose figures, but the figures were represented by holes punched in e cards. Each card was put in a machine not unlike a typewriter; boy looked at the figures, and as quickly as an operator could work the typewriter he perforated the card. Perhaps a hundred cards)uld be done right off. The cards were then placed in a tabulating achine, on which were a set of what looked like steel knitting edles. These needles were brought down on the card; where there



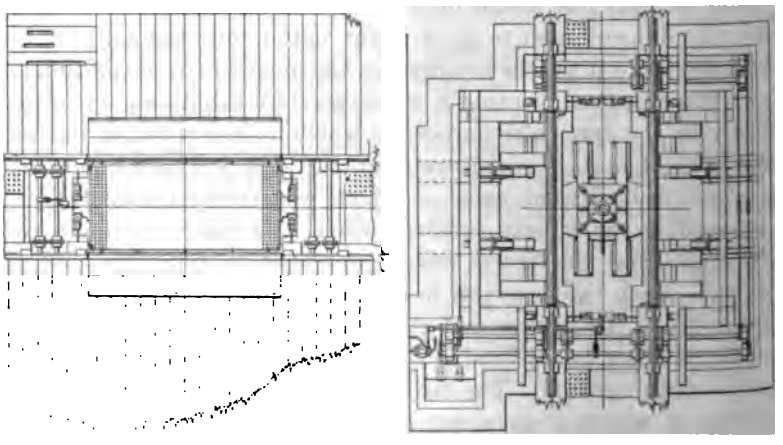


FIG. 21 STANDARD 20-TON HYDRAULIC WHEEL-DROP, L. & Y. RY.

a hole in the card the knitting needle would go through; where e was not a hole it would not go through. When the knitting lle went through, it went into a bath of mercury, and formed an tric circuit by means of which the number represented by the oration of the card was, by a set of figures in front of the operator, antly recorded. The figures could be tabulated very rapidly, and ırds made in £ *s. d.*, or tons of coal, gallons of oil, etc. This is a r interesting piece of mechanism which saves an enormous ɔunt of time.

here was one point with regard to engine-shed pits to which he ıred to direct attention. One of the leading American engineering railroad journals, in anticipation of the joint meeting of the Insti- ons, had recently been publishing an admirable series of articles ın running shed practice. The author of the articles thought t the bottom of the pit should be convex in section.

Ie thought that was wrong. A pit was required underneath the jine so that the engine could be properly examined, and as a large way had some miles of pits, their construction was worth consid- ıg. He allowed that it was more necessary in this country because engines had inside motion, whereas in America they had outside inders; but in the latter country compound engines were now being d with inside motion as well as outside motion. Therefore, the ought to be made in such a way that it was possible to walk quite ily along it, and the form described was bad because the bot- n of the pit was always greasy. If a man stood on such a floor his s were spread out and he might get hurt. It was greasy and dirty, l at some place in its length it was necessary to put in a drain ause grease did not run off easily. Another practice was to make bottom of the pit concave in section. Water was always present such a pit, and the man examining an engine always got his boots t. Neither in that form of pit nor in the one which he had pre- ıusly described could a piece of packing be put in to stand on if was desired to get up properly to do the work. He thought the tter way of making a pit—he did not say the best way—was with lightly sloping bottom, with a drain at the side covered with a rforated wrought-iron plate. If the pit was built in that form e water ran off immediately; it drained off near the exact spot which it came in, and the drain could easily be cleaned. The cking on which it was necessary to stand to examine the engine r level on the bottom, and the man could work comfortably with- t fear that when he was using a spanner for tightening up he

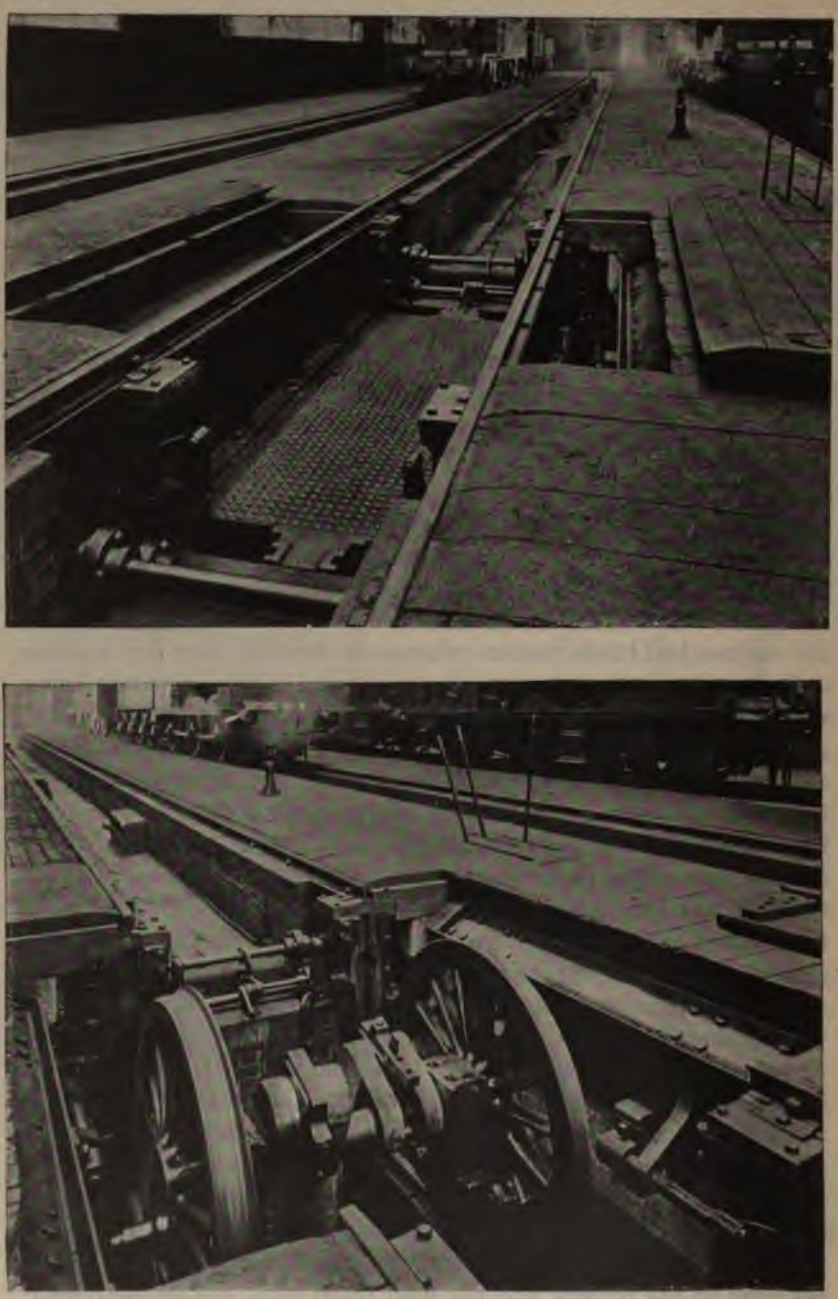


FIG. 25 HYDRAULIC WHEEL-DROP, BOTTOM SHED, L. & Y. RY.
Upper View: Top position empty. Lower View: Wheels lowered part way

would slip and fall to the bottom of the pit. In building an engine-shed pit it was always necessary to bear in mind the class of engine which would be dealt with in the shed. He had a theory, whether he was right or not he did not know, that the height from the bottom of a pit up to the center line of the motion ought to be about the average height of a man from the bottom of his feet up to his eyes, so that the center line of his eyes would be about opposite the center line of the motion which he had to examine.

JAMES M. DODGE[1] said he did not approach the subject in any way from the standpoint of a railroad man. He was simply a constructor of locomotive coaling stations, which had been built to suit the views of railroad men. It would be almost impossible for him to say anything of special interest to those engineers who were residing in this country, except in the most general way. For instance, in the United States, engineers were very far from arriving at any standard of practice. In order to give an idea of the extreme conditions which had to be contended with, he thought it would be of interest if he stated that the company with which he was connected had constructed locomotive coaling stations to accommodate in some cases as much as 40,000 tons of coal, so as to be directly available for the coaling of locomotives. In other cases there was no coal storage at all, reliance being placed upon the almost daily receipt of small quantities of coal. These represented the two extremes. In the one case there was no pit at all; it was simply a matter of coal and water, and not even sand. In the larger station to which he had referred, where 40,000 tons of coal were stored, every provision was made for pits, coal, water and sand. The most general practice in the United States was the use of the inclined trestle and the overhead track, if there was plenty of room.

When the coaling of locomotives had to be done in locations where land was valuable, and where it was quite impossible in some cases to make an incline of sufficient length, the use of mechanical appliances to fill the bins or pockets overhead was necessary. The balanced bucket type was used very largely in the United States. It was a rather simple apparatus, shown in Fig. 17. There were two buckets going down into the pit alternately, so that coal could be drawn from the bottom of a car directly into one of the buckets, the bucket elevated, and the coal passed to the overhead bin, or

[1] Mem.Am.Soc.M.E.

discharged into small cars and distributed. In other cases the vertical bucket type of elevator was used, or with a shorter incline a conveyor with either one or two chains and scrapers.

The managing men on all the American railroads were, unfortunately, so far as he knew, suffering from a lack of uniformity on the accounting side of railway management, with the result that there were no data available which were absolutely reliable as to the relative cost of coaling locomotives by the various types of apparatus described. That difficulty arose from the fact that they were still suffering from the misuse of comparative reports. By that was meant that a division superintendent on one road might have his reports compared with those of a division superintendent on another road, and the items which went towards making up the cost in the two cases were not identical. There was always a desire, if it was possible to do so, to shift expense charges on to some other department, with the result that very conflicting reports were obtained. He had himself seen reports made of the cost of everything connected with coaling at a large central coaling station, where the figures had been double those reported and claimed by exactly the same apparatus in another locality. That, of course, was perfectly ridiculous; simply on the law of average it would be impossible to get a very great divergence of results, with a number of items. He thought, however, that the condition of affairs was becoming better; and he knew that on some railroads, especially on the Union Pacific, they had gone so far as to try an experiment, which looked as if it were going to work out well, namely, of doing away with all sub-titles, such as master mechanics, engineers of bridges and the like, and having a superintendent, every important man below him on the division being an assistant superintendent. That experiment had resulted in some very interesting features. For instance, at present on some roads, the superintendent of bridges and the engineer of maintenance of way might be sitting back to back each at his own desk, and sometimes these men would amuse themselves by writing long letters to each other instead of turning round and talking the question over, simply because they happened to be in different departments. On the Union Pacific system these two men would now both be assistant superintendents, and if the man who paid more attention to the maintenance of bridges than anything else saw a baggage man (Americans spoke of them colloquially as "baggage smashers") delinquent in his duty, he had authority to correct him. The agent in charge of the station could also be chided, or corrected, or directed to do what-

ver was right and proper by any one of the assistant superintendents. He knew, of course, that by absorption a group of men of equal intelligence, all working for the good of a railway, must acquire through a term of years, much identical knowledge; at all events, they had almost the same opportunities for the acquisition of that knowledge. It was not possible to say exactly where one man's knowledge ended and another man's knowledge began; and it had consequently been found that every one of those groups of men of equal ages and equal intelligence, and having been in railroad business for an equal number of years, was competent to attend to 90 per cent of the duties of the others, provided they were all working under the management of the same man, and that the superintendent was their supervising officer.

HENRY FOWLER[1] said that while the subject under discussion, as previous speakers had remarked, was the question of terminals, he was personally interested in the question of repairs, which had some bearing on the point. Mr. Paget would, he thought, permit him to say that on the Midland Railway the number of engines usually in the shops was about ten per cent; the other fifteen per cent, to which he had referred, were engines which were stopped either for washing-out purposes or for some other occasional cause. There was much of great interest in the papers which their American friends had written, but unfortunately they had not had them in their hands long enough to be able to criticise them as effectively as they would like to do; but there were one or two points to which he desired to call attention. One was the very large mileage per annum they were able to get out of their locomotives. He believed that the Caledonian Railway Company, in some figures published in connection with the International Railway Congress, showed a very high mileage for British engines, but nothing compared with those mentioned in Pars. 160 and 161 of Mr. Forsyth's paper. He did not know whether Mr. Clark could say whether those engines were pooled, or whether they were run on a system which naturally appealed to an engineer who had to deal with repairs and maintenance, namely, the allocation of a locomotive to a particular man.

Another matter which from English practice seemed very strange, was the large number of men mentioned in one paper as having charge of particular work. If Mr. Clark could say whether that was general practice, or whether it applied only to places like East Altoona,

[1] M. I. Mech. E., Chief Mech. Engr., Midland Ry., Derby, Eng.

where he thought they reckoned to turn out an engine every five minutes during the whole of the day, it would be of great interest. The question of water softening was becoming a more and more serious one on the Midland Railway, particularly as for some reason or other the sodium compounds in many waters seemed to be increasing. That, he believed, was largely due to the fact that certain trade products were allowed to be put, rather more freely than railway engineers liked, into their water sources.

With regard to the question of the stock kept for repairs, he felt somewhat envious of Mr. Hughes, whose farthest station was 84½ miles from his headquarters, but he could assure him that he followed with much interest his system of delivery by stores vans. Mr. Paget had had more to do with casualties than he (Mr. Fowler) had, but he was able to say that on the Midland line the casualties were, with about 3000 engines, something like 50 per month. Those records made him wonder whether they were as far wrong as people sometimes said they were in continuing to use copper tubes, as Mr. Hughes had stated that about 20 per cent of his casualties were due to tubes. Personally he had not seen a tube casualty during the past eight days. Mr. Clark gave some very interesting figures (Par. 129) with regard to the cost per passenger engine per month. The point connected with those figures which naturally struck one who dealt with repairs was that the inspecting amounted to only 15 cents. This, he presumed, meant the whole of the work of examining the engines which was not done by the driver or fireman; but he would like to know whether that was so or not.

The point with which engineers in this country were not so much troubled as were engineers in America, was the question of staybolts. The use of copper staybolts was universal in this country, with the result that very few failures indeed resulted from this cause. Staybolts did not have to be examined in this country for breakage in the same way and with the organized system that was found necessary in the States. A point which was, he thought, of very great interest, not only to engineers, but to those who were concerned with the prosperity of railways, was the question raised in one of the papers of the relation between the locomotive and the traffic departments. Those who had experience of the arrangements which had been made on the Midland Railway fully appreciated that point. It was absolutely necessary that the two departments should work hand in hand, and not endeavor, as Mr. Dodge had said, to shift not only the expenditure, but all other trouble from one to the other.

HENRY L. GANTT[1] thought the time was particularly appropriate make a few remarks with regard to certain work which was being me by the Canadian Pacific Railway in Montreal, with which the embers were probably not acquainted. It was being done under Englishman, most of whose assistants were Englishmen, and results ere being achieved of which he thought in the next three or four ars a good deal would be heard. About eighteen months ago the esident of the Canadian Pacific Railway asked Mr. Vaughan, the sistant to the vice-president, who has charge of the shops, how ficient his great locomotive repair shops in Montreal were. Mr. aughan replied that he thought they were pretty efficient, but he as requested to have a report made on the efficiency of their opera-ons. In order to show the close relations between Canada and the nited States, Mr. Gantt thought it would be of interest if he stated hat the first people with whom Mr. Vaughan got into touch were the rm of Dodge & Day, of Philadelphia, and that firm asked him the speaker) to associate himself with them in making the report. ltogether about two weeks were spent by his colleagues and himself t the shops, and they had the pleasure of reporting that the efficiency vas quite as good as at any of the shops with which they were familiar, nd that the workmen and foremen were as capable as any of those vith whom they were acquainted. They were asked, however, to riticise, and they accordingly made a general criticism somewhat n the following lines. Although the large shop was being operated fficiently, and the company possessed good men on whom they were dependent, they had no means in the shop for perpetuating improved methods which might be developed by the workmen or by the various foremen. Some of the foremen were evidently overworked; it had previously been thought by the company that the foremen were incapable. Subsequent developments, however, proved that the foremen were not particularly incapable, for when their work was properly planned for them, they performed it with a very fair degree of efficiency.

The proposition which he and his colleagues made to the company was that a central planning department should be established, in which all the work of the shop should be planned for the different departments. The planning department as it was established there, though a very crude one, was based on the ideas developed by Frederick W. Taylor. It was found that the aggregation of different shops

[1] Mem.Am.Soc.M.E.

of which the repairing department consisted did not work harmoniously. Their first problem was to cause those shops to work harmoniously, that is, to have the different parts of the same locomotive ready in their proper sequence, and that was done through the central planning department to which he had referred. He had not sufficient time to give complete details of that department, which was run by a young Englishman who had served his time at Crewe, but stated that the working of all the different shops in the large locomotive repair works had been greatly harmonized. He was told recently by Mr. Vaughan himself that he did not now have to bother about the repairs of his locomotives, because everything went on so smoothly. That was one element.

Another element was that there was no provision in those shops for the education and training of workmen. Most of the workmen were French-Canadians who, when they were taught, were excellent workmen, but they had to be taught. A system was inaugurated of making investigators and instructors of the very best mechanics that could be obtained. Those mechanics investigated, for instance, the best method of turning a driving wheel, or of boring a cylinder; they wrote out detailed instructions as to how that work should be performed and the exact time needed for each operation; and then the workmen were taught how to perform those operations in the time set. As a compensation they were allowed pay, not for the time in which the expert could perform the work or in which he could show them how to perform the work, but they were allowed compensation for 25 per cent more than that amount of time. That system was working out very satisfactorily. The men receive their day rate in all cases, when they fail to make more by the piece rate. The following was one of the instruction cards. On one side appeared a drawing of the piece to be operated upon.

LIST No.: 17 L 31

ing No.: 17 L 31

e: Driving Axle-box

: All Cast-steel Boxes

iule No.: 17 L 147 Issue: A

ation:

Slot Crown Brass Fit

ation: No. 3 Material Cast: S

ine: Bertram Single Slotter No. 24

Steel: Edgar Allen

f Pieces: 1

: 1.3 man-hour per piece

f Men: 1 Date: 3-22-10

Equivalent:

Piece: 1.65 hour

ading on the back of the card was as follows:

ed Instructions	Tool Used	Depth of Cut in In.	Feed in In. per Stroke	Stroke per Min.	Min. Allowed
and Layout.....	—	—	—	—	10.0
.....	—	—	—	—	2.0
lot Crown Fit	1 PRSC	15-32	1-16	18	21.0
Tool.....	—	—	—	—	1.0
lot Corners.....	1 PRSB	1	1-16	18	14.0
Tool and Grind....	—	—	—	—	2.0
lot Crown Fit.....	1 PRBC	1-32	1-16	18	24.0
....	—	—	—	—	4.0
gus Shop C. P. R.	Total Min.....				78.0
	Total Hr. per Piece.....				1.3

The following shows the back of an instruction card for milling both outside faces of twelve cast-steel driving boxes:

	DETAILED INSTRUCTIONS	Tool Used	Depth Of Cut In Inches	Feed In Inches	Speed R.P.M.	Speed in Feet Per Min.	Hours Allowed
	CHANGE CUTTERS AND PREPARE MACHINE FOR 1st PIECES						60
1	SET UP AND CLAMP 12 BOXES						120
2	SET CUTTERS TO DEPTH						5
3	MILL 1st SIDE	8 RSS	1-4	1 1-2	22	46	113
4	TURN OVER AND RESET BOXES						145
5	SET CUTTERS TO DEPTH						5
6	MILL 2nd SIDE	8 RSS	1-4	1 1-2	22	46	115
7	REMOVE 12 BOXES						50
						TOTAL MINUTES	613
	B D. ANGUS SHOP C P. R					TOTAL HOURS PER PIECE	10.2

Those cards were now being printed in lots of 50, and distributed over the entire system from Montreal to Vancouver. With the cards were sent a series of blue prints showing the standard shapes of tools, also developed by Mr. Taylor, which had been found most efficient in the cutting of metals, and also the description and capacity of each of the machines in the shops. The other shops would be invited to develop instruction cards which perhaps might be better than the one he had described; and a bureau would be established in Montreal, where the standard method of doing machine work would be kept, and where the best knowledge of how to do any machine operation needed on the road would be available.

ARTHUR D. JONES[1] said that in the diagrams of the sheds described in Mr. Paget's paper, the depth of the pits was not given, and he would be much obliged if the author would supply that information for both types. He desired to be allowed to emphasize the great importance of the provision of wheel drops in running sheds,

[1] M. I. Mech. E., Loco. Dept., Lancashire & Yorkshire Ry., Horwich, Eng.

int already alluded to by the president. With those appliances e mechanic and a laborer could take out a pair of trailing engine ieels from a six-coupled tender engine in thirty-five minutes, where- if hydraulically worked sheer legs were used, one hour and twenty nutes would probably be occupied. Further, the leading pair of dial wheels from a four-coupled passenger-tank engine could be ken out in a quarter of an hour by one mechanic and his laborer. ie drops were also very useful in emergencies for dealing with hot les, or replacing springs quickly. A good deal could be said about e relative merits of round and straight sheds, but from what he id seen of the ordinary type of straight steel (not double-ended), ere was really no difficulty in dealing with the engines in a very onomical manner. The round shed, however, appeared to have i advantage in the question of lighting. He would like to ask Mr. iget to explain how dead engines were dealt with in round sheds. The list of examinations given in Tables 1 and 2, showed a ost complete system. He would be glad if Mr. Paget would give me idea of the staff employed in making those examinations, as imagined it would be a very considerable one. As, however, fail- es on the road were very expensive, the expense involved might more than saved. Mr. Paget mentioned (Par. 42) that links of enty engines were sometimes arranged for. That appeared to m a large figure, and perhaps Mr. Paget would be good enough to y if it referred to shunting engines only. There could be no doubt out the advantage of allotting engines to regular drivers, as this sulted in better all-round efficiency. But while the earnings of a omotive had to be kept up by the engines being worked as much possible, the hours of the men, on the other hand, had to be kept wn. The provision of relief was one of the most important matters running-shed foremen to look after, as it was a very costly mat- r.

Mr. Paget referred (Par. 49) to the question of the compilation of rking costs. There could be no doubt that the question of statis- s was one of great importance to the management. Statistics tained in the way the president mentioned were of the greatest istance to any running superintendent, not only for supervision rposes, but also to enable him to put his finger at once on any ctuation in expenditure, or miles run per engine-hour. It would of great interest if Mr. Paget could give a short description of the omotives mentioned in the various classes (Tables 1 and 2); in the per the wheel base only was mentioned. A good deal had been

said in the press recently about the want of employment for between sixteen and eighteen years old. Running-shed work he thought, provide an excellent opening for such youths. I been greatly interested to hear the Lord Mayor of Birmingh that he loved to see smoke. He wished they could get Ma Lancashire to think the same, and he thought that was on Lancashire might very well copy from Birmingham.

J. E. SAGUE[1] said that he had had considerable experience in ling locomotives, and had been for two years the locomotive s tendent in one of the British Colonies, the Island of Jamaica, he saw something of English locomotives. Later on he wen the Schenectady Locomotive Works, and tried to find out h American locomotive should be designed, and had perhaps con his education by trying to design some locomotives for the M Railway of England. He had an interesting experience, worl that connection with Cecil W. Paget, the author of the paper had been read. Mr. Paget had compared notes with him on t ject of the advantages and disadvantages of the American a English locomotive. Mr. Paget showed him conclusively that United States sufficient attention was not paid to the nece keeping the locomotives running without failures on the roa showed that in the Midland traffic into London, it was extrem portant that no engine failure should occur. There was a str trains going into London in the early morning, and it was e that every train should keep its place in the line, and that n motive should break down.

The Public Service Commission was concerned with the reg of railways in the State of New York, some of its functions bei ilar to those performed in this country by the Board of Tra it had recently been necessary for the Commission to comp engine-service on various railways. An extraordinary dif had been found; on some railways the standard was ext high, and on others it was low. He felt that each An engineer interested in locomotive construction and running not do better while in this country than to examine the runnin practice, the inspection of locomotives at terminals, and the ordinary precautions which were taken to prevent engine f It all cost a great deal of money, but an engine failure was

[1] Mem.Am.Soc.M.E.

the most expensive propositions in railway operation. It might cost $25 to repair a broken eccentric strap, and the locomotive man was very apt to look at that sum as if it were the final cost. But an engine failure meant that passengers might be delayed for perhaps an hour in reaching their terminal; that freight trains, especially on American lines where they had single and double tracks, might be delayed; that new meeting points were made, and the whole service was demoralized; so that $2500 might readily be put down as the expense of the engine failure instead of $25. Engine failures ought to be stopped as much as possible, and American engineers had to learn that lesson from England, and he felt they were learning it fast.

English engineers had arrived at beauty of design earlier than American engineers. He had noticed the previous day in the Liverpool station a locomotive dated 1866—an extraordinarily old one from the American point of view. The interesting thing about the locomotive was that it looked reasonably modern—what one would term in the United States an engine designed according to modern lines, with straight boiler, smooth dome casing, beautiful finish, and the tender designed as though it were to be built at the same shop with the engine. He wondered what an American engine designed in 1866 would look like.

In trying to build American locomotives so as to prevent engine failures, it had been found that the breaking points in American designs were sometimes hidden. For instance, a cross-head would have a small piston rod fit because it was cheaper and easier to make, but it was now thought better to have these breaking points where they could be inspected. They had copied English practice in that respect. He had learned a good deal in engine design from English practice, and believed that it was only by comparison of the work of the two countries that the best results could be achieved.

CLOSURES [1]

F. H. CLARK, in reply, said he had been interested in the figures given by Mr. Hughes with regard to the cost of stores per engine He did not know that he had ever seen any similar figures for American roads, but he imagined that the cost of stores on American railroads would run somewhat higher than the figures given by Mr.

[1] Messrs. Whyte, Forsyth and Vaughan did not desire to present closures. ——EDITOR.

Hughes, although he did not know exactly what was included. He thought that, generally speaking, the English roads held the advantage over American roads to a very considerable extent for the cleaning of engines. Some of the American roads paid a very great deal of attention to cleaning, and, while it was expensive, they felt they received value for the money spent. Their engines certainly looked very much better, and it was no doubt easier to detect fractures which might cause trouble on the road. Mr. Hughes seemed to be a little dubious about the American practice of shimming tires. He (the speaker) suggested that at some time when Mr. Hughes was in a pinch he should try it. Americans did not use it generally, but it was found that occasionally the practice had to be adopted in order to keep an engine going, and they very seldom had any trouble with it. The president had made some remarks with regard to wheel drops or drop pits, as Americans called them. They were the rule in the United States. There might be some installations of cranes or sheer legs, but, on the other hand, there were a good many drop pits such as the president described.

With reference to the number of engines in shops, it was American practice to have about 10 per cent of the engines in shop at a time. Sometimes the figure ran a little above that, but it was generally a little below 10 per cent, which was considered a very good figure in the United States. He rather liked the president's design of an engine house floor. The figure of 15 cents (Par. 129) to which Mr. Fowler referred, was not 15 cents a month, but 15 cents a day. All the figures given on that page were figures per day; he should have left out the words "per month" in the table. The figures were assembled by the month, and to arrive at the averages he took the average figures for eight months.

In reference to the remarks which had been made regarding the number of men in the organization, he thought Mr. Fowler was referring to Mr. Forsyth's paper dealing with the Pennsylvania Railroad organization at East Altoona. That was a rather large plant; the average number of engines turned at other points was considerably less than at that point, so that as a result fewer foremen and men were needed.

CECIL W. PAGET,[1] in reply, said that he was not able to answer offhand the question Mr. Hughes had asked with regard to the val

[1] M. I. Mech. E., Genl. Supt's. Office, Midland Ry. Co., Derby, Eng.

of stores in stock per engine, but he would do so in the Proceedings, and he hoped the figures he gave in his answer would be as satisfactory as Mr. Hughes' were. Mr. Hughes had made a great point of cleaning being a good investment. Personally he thought it was a good investment, for the reason which Mr. Hughes implied, although he did not actually say it, that when an engine was not clean, it was impossible to see whether or not it was in a proper condition, and flaws and fractures were far more easily hidden in a dirty engine than in a clean one. Mr. Fowler had already given the information that the engine failures on the Midland Railway were about fifty a month.

With regard to Mr. Dodge's remarks on the question of supervision in running sheds, it was no doubt very desirable that the old-fashioned plan of particular men not being allowed to do certain work, should be broken down as far as possible. It was no doubt desirable that it should be impossible for a man to say, "This is my work and that is the other man's work, and nobody else can do that man's job." He was afraid, however, that in this country matters were not ripe for such interchangeability of supervision as Mr. Dodge mentioned, although from his point of view no doubt it was very desirable.

In reply to A. D. Jones who asked what was the depth of the pits on the Midland Railway, the pits were 2 ft. 10 in. deep. With regard to the staff that made the examinations, although it would appear, owing to the great emphasis laid on the fact of engines being examined, that it required a special staff, it did not. The ordinary staff of examining fitters carried out such examination of the engines as was called for by the state of the engine at the periodical examination, the ordinary examinations of course being mainly carried out by the drivers and firemen. Mr. Jones also mentioned the number of engines in a link. On the Midland Railway there were links of as many as twenty engines on freight-engine work as well as shunting work. That was the usual number.

With regard to the question of relief, he did not think there was the same difficulty in the United States that there was in this country, where they were obliged to restrict the hours of duty of every man to twelve. Nobody wished to work any man more than the ordinary hours, but as there were a great number of railroad men present, it was almost unnecessary for him to say that it was extremely difficult sometimes to prevent occasional long hours. Mr. Jones mentioned that as part of the running-shed work. It was, generally speaking, and he only mentioned it then because he thought it might be of

interest if he said that on the Midland Railway it was dealt with differently than on other railways in the country, somewhat on the lines of the train dispatching department in America. The control department knew the positions of the trains on the line over such sections as were equipped with the train control or the train dispatching, which was practically the same thing, and since the operating department, as opposed to the running-shed people, knew the positions of the trains, they were able more efficiently to provide relief and to control and prevent long hours.

Mr. Sague mentioned that the designers of American engines had learned something from English practice. He hoped Mr. Sague had also noticed in the English workshops and the English round houses a good many of the influences of American practice on English practice. Mr. Sague had also spoken very modestly of his own work in connection with the design of engines. He did not think better evidence could be quoted of Mr. Sague's ability and success in designing locomotives than the enormous, yet beautiful, engines which were turned out by the Schenectady works of the American Locomotive Company.

SYMPOSIUM ON HIGH-SPEED TOOLS

No. 1291*a*

HIGH-SPEED TOOLS AND MACHINES TO FIT THEM

By H. I. Brackenbury, Newcastle-on-Tyne, England

M.I.Mech.E.

Introduction of High-Speed Tool Steel. Those engineers who saw, at the Paris Exhibition in 1900, a lathe running at a high speed with a tool with its point red-hot removing a dark blue chip, felt that they were witnessing the beginning of a revolution in tool steel and in machines fitted for its use. This revolution has now taken place and we are slowly accommodating ourselves to the new regime, but many changes have had to be made, not only in the direction of making far stiffer and more powerful machines, but also in our views regarding the values of certain types of machines for producing certain classes of work and the grouping of machines.

2 *Gradual Extension of its Use.* The use of high-speed steel for tools has been gradually extended, the old temper steel having to retreat from one position to another. For some time high-speed steel was considered to be useful only for rough cutting with the tool of the usual lathe form. Then its use was extended to twist drills with wonderful result; again its use was considered problematical in capstan and turret lathes where high speeds with copious supplies of oil or lubricant were already in vogue, but now no maker of such machinery would advocate the use of anything but the best high-speed steel. Milling cutters of all descriptions are made of high-speed steel, and although the toolmakers still advertise the alternative of temper steel, those who have had experience of the high-speed milling cutters would not think of ordering cutters of temper

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steel, unless the cutter was only required to accomplish a small amount of work, in which case it would be policy to run slower rates with a cheaper tool. Reamers, chisels for chipping hammers, rivet snaps for pneumatic and hydraulic riveting devices, have all been found to give the greatest satisfaction when made from high-speed steel. Examining such a list of uses, it becomes apparent that this steel has other properties besides that of retaining hardness at high temperatures.

3 *Useful Properties of High-Speed Tool Steel.* The three properties of modern high-speed steel, are:

a The edge can be made very hard
b Hardness retained up to a high temperature
c Toughness

4 These properties are what make the steel so universally useful, but when high-speed steel was first introduced it had only the property of retaining its hardness up to a high temperature. Much has been written about high-speed tools, their composition, highest cutting speeds, power absorbed for various cuts, etc., by such competent authorities as Mr. F. W. Taylor, Dr. J. T. Nicolson, Mr. J. M. Gledhill and others, and it therefore seemed better to the author of this paper to treat rather of workshop conclusions than to examine further into matters which have been so ably dealt with by the above writers.

5 *Classes of High-Speed Tool Steel.* There are a few points which should be stated at the outset. There are three classes of high-speed tool steel, which will be called in this paper:

Class A For cutting mild and medium steel
Class B For cutting hard steel such as tires, etc.
Class C For cutting very hard steel and for use in cases where a sharp and lasting cutting edge is required; especially useful in cases where deep cuts with fine feeds are used.

6 *Power required to Remove Material.* More power is required to remove a thin wide chip than a chip of double the thickness and half the width, that is, to remove a chip 1 in. wide with a feed of $\frac{1}{8}$ in. requires more power than to remove a chip $\frac{1}{2}$ in. wide with a feed of $\frac{1}{8}$ in. This is less noticeable with tools with sharp edges. Tools with blunt cutting angles require more power than tools with sharp cutting angles to remove the same amount of material, the objection to sharp cutting angles being that the edge is apt to break.

7 The total power used for a given cut, including the power sorbed by friction in the machine, increases at a smaller ratio an the increase in cutting speed, in other words, less horsepower used per pound of material removed at high speeds than is used ; low speeds. This is only true up to a certain point.

8 *Difficulty of laying down Rules for Cutting Speeds.* Figures of ıe speeds and feeds and depths of cuts which can be taken with ıthe tools of high-speed steel under ideal conditions are interesting, ıd are very useful in showing in what direction we should modify ır old methods and design new machines, and to what perfection e should strive; but the author does not think these figures are f much use as a guide to what is actually performed in the general ın of workshops. There are so many variations in the actual ɔnditions that, without a careful study of each class of case, it is ifficult to say what is the best rate to cut at. Mr. Taylor, in his ıost valuable work, The Art of Cutting Metals, gives twelve var- ıble elements, but even this number does not cover the whole round, and such questions occur as one man working several ıachines and several tools cutting simultaneously. Thus, on certain ork where there is a large amount of repetition, it has been found pos- ible to employ to advantage lathes with two saddles and three rests to urn work from 3 ft. to 4 ft. long. As one man looks after two of hese lathes he has to keep six tools at work on very hard steel. It is uite evident that under these circumstances it is important that the ools should not require changing often, as this would cause the ıthe to be idle for a portion of the time, and too much of the work- ıan's energy would be used up in changing the tools and setting in he cuts. One of the advantages of the use of high-speed steel in he above case, is that the tools will generally run for the day with- ut requiring to be ground. This work could be done at higher utting speeds using one tool and grinding more frequently; the sult would be more effective to watch but less satisfactory to pay for.

9 *Cutting Angle.* Regarding the question of cutting angles, areful experiments have shown that the sharper the angle is the less he amount of power required to remove a given amount of material, ıe feed and depth of cut remaining constant. On the other hand, ıe sharper the angle is, the more likely is the cutting edge to crum- le or break, and the smaller is the body of steel to conduct away ıe heat generated by cutting. In no well-regulated machine shop do ıe workmen grind the tools they use; grinding machines with trained perators are now almost universally employed for this purpose.

10 *Value of Standard Angles.* The importance of working to standard angles is obvious, and the fewer the standards the better, so long as the loss in cutting efficiency is not greater than the gain in grinding and forging tools to a small number of standards. The question of what standards are required, must depend on the variety of work and material and quality of machines in a shop. The author strongly deprecates becoming a slave to standards when many variables are involved, and feels that it should be the duty of a capable shop manager or foreman to experiment with tools of various cutting angles when he had a suitable run of work.

11 *Importance of Changing Angles as Quality of Tool Steel Improves.* High-speed steel has improved in the past few years and will probably improve in the future, and with these improvements we find the cutting edge remains sharper for a longer time and the cutting angles may be made more acute. As an instance, when turning axles at the most convenient feed and speed and depth of cut, the belt failed to drive the lathe when using the standard round-nose tool. A tool was ground with a smaller radius on the nose, a straighter cutting edge, and a sharper angle; the belt was found to have sufficient power to drive the lathe with the full depth of cut when this tool was used, and the tool was adopted as the standard for this particular work. The reasons for the above are:

a The cutting length of the tool was diminished, less power being required to take a thick narrow chip than a thin wide chip.

b The sharper angle presents less resistance to the chip after it is sheared from the body of the material. Such a tool would not have been suitable for the general practice of the shop where heavy feeds are used.

12 The following are the particulars of the case, and are interesting as showing what use can be made of high-speed steel even in an old machine, a question which will be dealt with further on:

MACHINE	AGE	MATERIAL
Lathe 15-in.....	Over 30 years.....	Axle Steel. Breaking 38 tons per sq. in. Elongation 24 per cent

Tool No. 1. Clearance 5 deg., side slope 13 deg., cutting angle 72 deg.
Tool No. 2. Clearance 5 deg., side slope 25 deg., cutting angle 60 deg.
Speed 52 ft., feed $\frac{1}{16}$, depth of cut $\frac{1}{4}$ in.
Cu. in. per min. removed, 19.5
Lb. per min. removed, 5.5.

3 *Use of High-Speed Tool Steel on Turret Lathes.* On turret lathes highest class of high-speed steel is now largely used, and tools ı a very sharp cutting angle are employed. A test carried out he works of Alfred Herbert, gave the result shown in Table 1.

BLE 1 REDUCING A MILD-STEEL BAR FROM 1¼ IN. TO ¾ IN. IN DIAMETER AT ONE CUT

Tool	R.P.M.	Cutting Speed Ft. per Min.	Feed per Revolution	Feed per Min.	Weight Removed per Min. lb.
on steel	149	58.5	0.0134	2.01	0.753
C special high-speed steel	470	185	0.05	23.5	8.8125

Tool clearance angle 7 deg. Side slope 35 deg. Cutting angle 48 deg.

4 *Economy in Power.* The pressure of the chip on the tool in s per square inch, cutting on steel of a tensile strength of 25 tons 44 per cent elongation, was 75 tons, which is about 25 per cent than results given with tools of which the cutting angles range n 65 to 70 deg.; part of this reduction was probably due to the keen ting edge which this special high-speed steel maintains. The ɔle of the tests worked out as follows, omitting one exceptional e:

Tests	Horsepower	Lb. per Min. Removed	Lb. per H.P-Min.
ts made 1909			
ighest Figure	14.4	7.58	0.52
owest Figure	6.1	2.01	0.33
ıchester Experiments, 1903			
ighest Figure	8.94	4.41	0.49
owest Figure	17.19	5.6	0.32

5 The 1903 figures represent net horsepower at the tool, but the 9 figures include all losses in the machine.

6 *Twist Drills.* Perhaps the most striking instance of the value ıigh-speed steel is given by the use of twist drills. The improvent obtained by the use of this steel for drills is more easily grasped ın in the case of turning tools, as there are far fewer variables. ⁄en sufficient power, a high-speed drill does three times the amount work and requires grinding less frequently than the temper-steel lls. The author is not one to advocate the policy of scrapping old material, but in the case of twist drills, where any quantity work is required to be done on steel, he advises the use of nothing

but high-speed steel drills. In Table 4 of the Appendix is given the ordinary practice with both temper and high-speed twist drills, and no minute inspection is required to detect the superiority of the latter. One instance is given here of a drill $\frac{3}{4}$ in. in diameter passing through a cast-iron block $2\frac{1}{2}$ in. thick in 8 sec., which is equal to a travel of $18\frac{3}{4}$ in. per min.

17 Space does not permit, nor is it necessary, to extol the further uses of high-speed tools, but some figures of actual performance are given in Table 5 (Appendix No. 1).

18 *Full Advantage not yet taken of High-Speed Tool Steel.* Although considerable use is made of high-speed steel in engineering workshops, the author ventures to say that, generally, full advantage is not taken of its cutting powers. Certainly speeds have been greatly increased, but they have not been increased in the proportion warranted. No doubt valuable economy has been effected by the increased speeds, and the length of time tools run without the need of grinding. We should not content ourselves with these results, but strive to use to the full the powers which the steel makers have put in our hands.

19 *Savings which Can Be Made.* The author thinks that, although the rapidity of production with high-speed tools has been well emphasized during the last few years, insufficient attention has been given to the accompanying savings. Where full use is made of modern machinery the production, in so far as roughing out goes, is three times what it was under the old conditions. This means that only one-third the number of machines, one-third the amount of space, one-third the number of operators, one-third the amount of shafting and about one-half the amount of supervision, are required to produce the same amount of work. Further, although the power required to drive machines capable of making full use of high-speed steel is very large the power absorbed for each pound of metal removed is less for high-speed than for low-speed machines.

20 *Machines for Roughing Out.* There is, in the author's opinion only one way in which the full saving may be made, and that is by setting aside certain machines for roughing and roughing only. It is quite unnecessary to replace all or even many of the old machines, which have quite enough power to carry the finishing cuts at good speeds, nor is it desirable to use either the same class of machinery or labor for roughing out as for finishing.

21 *Use of Old Machines for High Speed.* There are a number of workshops where there is not the inclination nor, owing to trade

ression, the capital to buy many new machines. In such cases
ch may be done by making a judicious selection of the heaviest
he existing machines and increasing their belt speed, so that high
eds may be run with the back gear in. In some instances, the cones
e been removed and replaced by wide pulleys, speed changes
ig provided for by means of sliding gears. Fortunately the Eng-
machine builders of the past did not hesitate to put plenty of
ght into their machines, so that, by increasing the driving power,
ellent results may be obtained, but it is generally necessary to
new gears. Fig. 1 shows an account of work produced by the
ve method by machines over twenty years old.

ERAL REMARKS ON MACHINES FIT FOR THE USE OF HIGH-SPEED STEEL

2 *Power which may be Employed Depends on Stiffness of Work, not on Size of Machine.* An idea what saving in cutting time has
n made by the use of high-speed steel can be gathered by a com-
son of the power allowed for machines designed before and after
introduction. Engineers have also grasped the fact that the
er which may be usefully employed depends upon the stiffness
he work and not on the height of centers in the case of lathes or
length of stroke, etc., in the case of other machines. Thus we
instances of 12-in. center lathes designed to use 50 h.p., which
bout ten times as much power as was allowed for in any of the
high-speed lathes. This increase in power must be accounted
by a desire for increased depths of cut and feeds as well as in-
sed speeds. There is no doubt that the interest awakened by
introduction of high-speed tool steel has called so much attention
he subject of roughing out work that many improvements have
ly been made which might have been made in earlier times.
author well remembers cases where recourse was had to putting
e belts, one on the top of the other, to increase the very limited
power of some lathes.

3 The following are some examples of increases in horsepower
vided:

Turret lathe for 2¼-in. bars increased from	2	h.p. to	10 h.p.
Lathe 6-in. center bars increased from	1	h.p. to	4 h.p.
Lathe 10-in. center bars increased from	2½	h.p. to	10 h.p.
Lathe 14-in. center bars increased from	5	h.p. to	20 h.p.
Lathe 36-in. center bars increased from	20	h.p. to	60 h.p.
Lathe 60-in. center bars increased from	30	h.p. to	100 h.p.
Slotting-machine, 12-in. stroke increased	9	h.p. to	15 h.p.

EXAMPLES OF WORK ROUGH TURNED ON LATHES OVER TWENTY YEARS OLD.

Apprentice Labour.

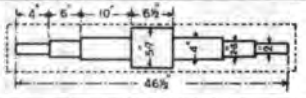
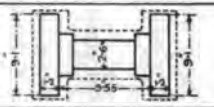
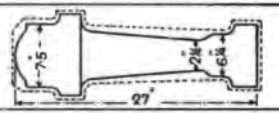
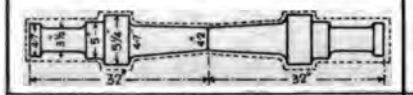
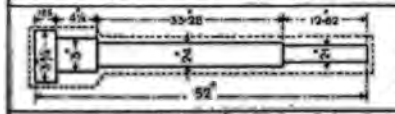
SAMPLE JOB.	ARTICLE	MATERIAL	WAGES RATE	ACTUAL TIME TAKEN.	TOTAL COST + BONUS.	FEEDS REVOLUTIONS.	REMARKS.
	SHAFTS FOR MOTOR GENERATORS	FORGE STEEL	2¼d PER HOUR	FROM 1 HOUR TO 1½ HOURS.	FROM 2·8d TO 4·2d	24/96	PARALLEL FORGING NUMBER OF DIAMETERS VARY
	MIDDLE EXTENSION SHAFT FOR BALANCER	FORGE STEEL	DITTO.	3½ HOURS.	9·8d	16/30	OVER 1" OF MATERIAL TO TURN OFF ALL OVER.
	CONNECTING ROD	FORGE STEEL	DITTO.	4½ HOURS	12·6d	20/40	EXCESSIVE AMOUNT OF MATERIAL TO TURN OFF
	WAGGON AXLE	FORGE STEEL	DITTO	6½ HOURS	17d	12/20	ROUGH TURN CLOSE TO FINISHED SIZES AND FINISH ENDS.
	SPINDLE	FORGE STEEL	DITTO	1 40/60 HOURS.	4·6d	32/78	ROUGH TURN FOR GRINDING. ·03 LEFT ON
	VERTICAL SHAFT.	FORGE STEEL	DITTO	1 20/60 HOURS.	3·7d	12/14	ROUGH TURN ALL OVER.
	ENGINE AXLE	FORGE STEEL	DITTO	5 10/60 HOURS.	15·8d	16/28	FORGING PRACTICALLY PARALLEL R. TURN & FACE ENDS.

Fig 1

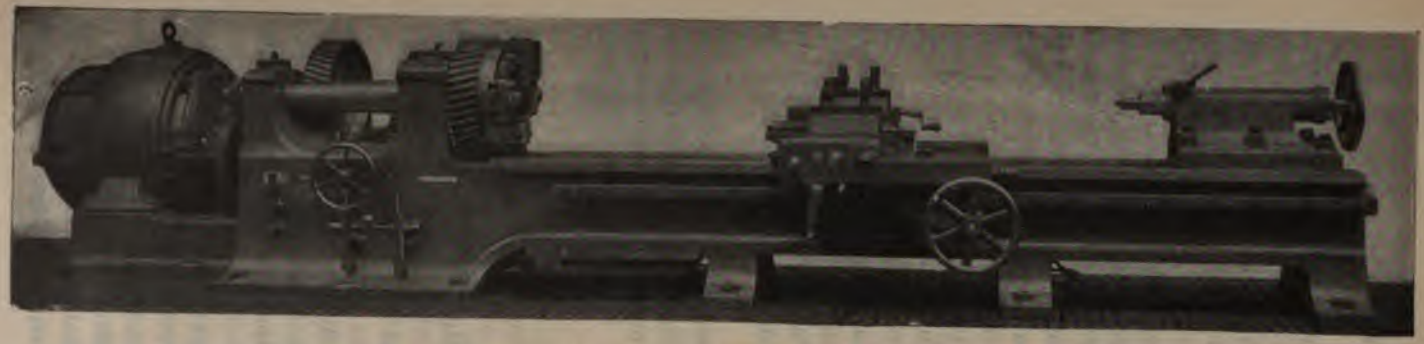


FIG. 2 TWELVE-INCH CENTER LATHE WITH 50-H.P. MOTOR

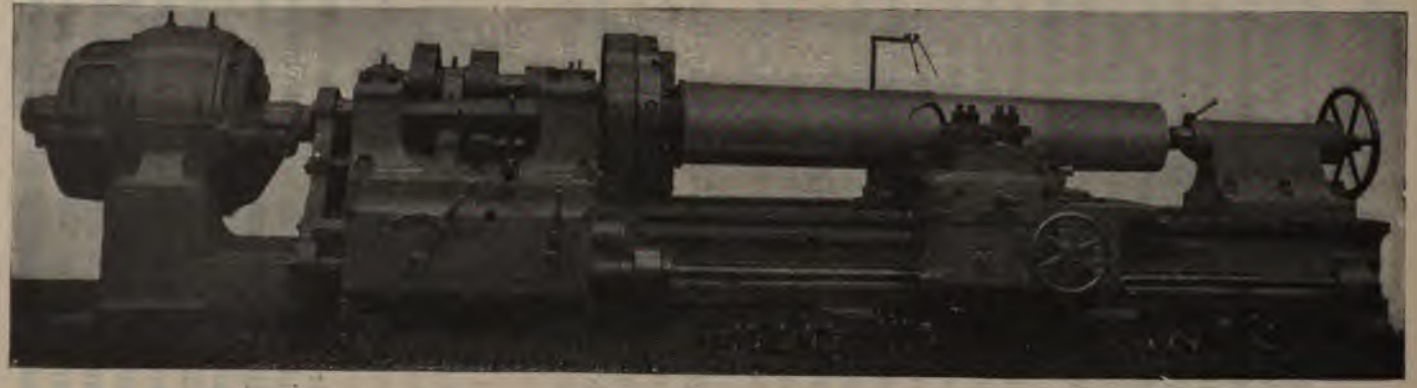


FIG. 3 EIGHTEEN-INCH CENTER LATHE WITH 60-H.P. MOTOR

Special cases of high power are: 12-in. center lathe, Fig. 2. 50 h.p.; 18-in. center lathe, Fig. 3, 60 h.p.

24 The 18-in. center lathe took a test cut on steel 1½ in. deep with a ¼-in. feed, at a cutting speed of 28 ft. per min., the consumption of power being upwards of 80 h.p.

25 *Limit of Power Applied.* There seems to be no finality as to the amount of power which can be applied to a machine. We find a milling machine described as capable of removing 1400 lb. of steel per hr. which would entail a consumption of not less than 92 h.p. Such a machine may be economical when it can be employed on a continual run of work requiring such cuts, but would be a serious charge when employed on lighter cuts. In the desire for rapid production from machines we must be careful not to overlook the consideration of the cost of power and value of material cut to waste in cases where the work could be made nearer to the size in a more economical way. The fact that by the use of high-speed machines a ton of cuttings can be made at a labor cost of 8*d.*, must not make us forget that someone has to pay for a ton of material and 7*s.* or 8*s.* for power.

26 *Laws regarding Limit of Weight and Power of Machines.* It is impossible to lay down any law regarding the limiting point of the weight and power of machines, as the number of variables which enter into consideration is so numerous. There are, however, three principal governing factors, namely:

a The length of time the machine will be used for heavy cutting.
b The length of time the machine will be used for light cutting.
c The length of time the machine will be at rest.

During *a* the machine is used efficiently; during *b* more is being paid for power and capital charges than if a lighter machine were used; during *c* more is paid for charges than in the case of a lighter machine.

27 These considerations evidently point to the importance of using heavy machines for roughing only, but there are many cases where this cannot be done. Take, for instance, the case of a drilling machine which is generally employed to drill and ream holes of 1 in. in diameter, but occasionally has to drill holes 3 in. in diameter. In such a case it would be a mistake to install a machine capable of

illing the 3-in. holes at a quick rate, as the proportion of stand- g to working time is very large for a drilling machine, and the time ring which the machine would be employed at its full power would very small. Some attempt has been made by means of the curves ig. 4) to show the tendencies of these various factors, but of course ch case must be taken on its own merits. In the case shown by e curves, the most economical results are given by a machine cost- g between £400 and £600, but if the finishing and setting times e reduced, a higher-priced machine would be more economical.

TABLE 2 EXPLANATION OF FIG. 4

oughing time is taken arbitrarily to be 0.2 $\left(\frac{1000}{c}\right)^{1.5}$ hr.

re c = cost of machine in £. Machine charge = $\frac{c}{1000}$ shillings per hour. Wages = 8*d*. per

Setting-up and finishing time = 1½ hr. on any machine.

Cost of Machine, £	Roughing Cost, *d.*		Setting-up and Finishing Cost, *d.*		Total, *d.*
	Machine	Man	Machine	Man	
200	5.4	17.9	3.6	12	38.9
400	3.8	6.3	7.2	12	29.3
450	3.6	5.3	8.1	12	29.0
600	3.1	3.4	10.8	12	29.3
800	2.7	2.2	14.4	12	31.3
1000	2.4	1.6	18.0	12	34.0

8 *Objections to Stepped Cone.* The stepped cone is rapidly be- ing obsolete, except in the case of small machines. The obvious dvantages of this method of changing speed are the trouble, and he case of boys, the danger of throwing a heavy high-speed belt n one step to another and the variation in power available from different belt speeds (Appendix, Table 6).

9 Speed changes are provided for by means of sliding gears in case of medium sized machines and variable-speed motors in the of larger machines. Such motors, worked on the direct-current e-wire system, give a large range of speed which is excellent, but well to notice that at certain speeds with light cuts the efficiency notor and machine may be far from good. Curves on Figs. 5 6 show the electrical horsepower at various speeds for a large e, the feed and depth of cut, about 0.2 in. by 0.2 in. on 40-ton ile steel (a light cut for this lathe), remaining constant for each

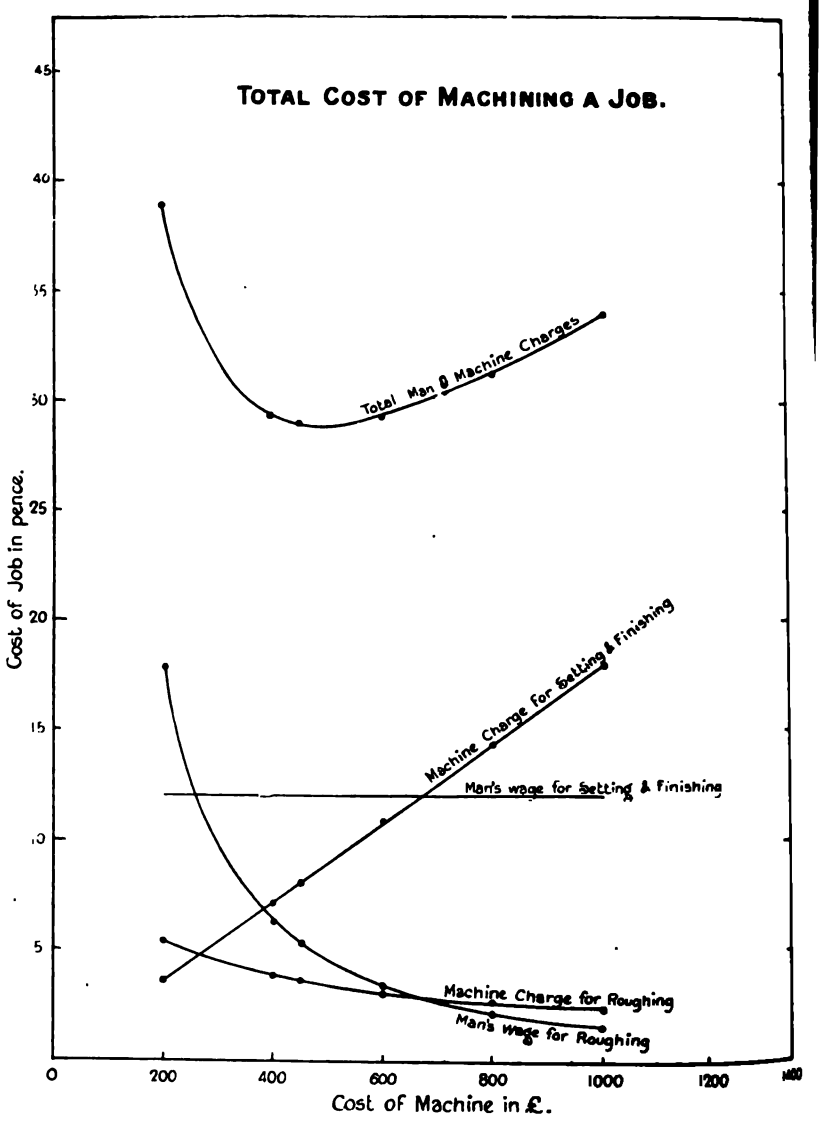
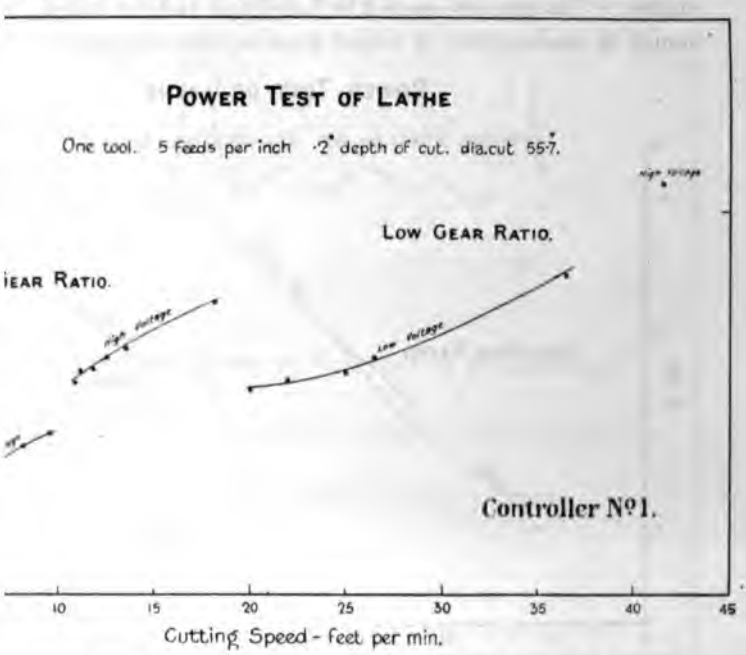

TOTAL COST OF MACHINING A JOB.
Total Man & Machine Charges
Machine Charge for Setting & Finishing
Man's wage for Setting & Finishing
Machine Charge for Roughing
Man's Wage for Roughing
Cost of Job in pence.
Cost of Machine in £.
0
200
400
600
800
1000
1200
5
15
20
25
30
35
40
45

FIG. 4

rves. It will be noticed that there is a drop in efficiency ange from the low voltage to the high voltage, and an extra- gain in efficiency when a change is made from the high nd high gear ratio to the low voltage and low gear ratio, t being that practically the same amount of power has to or at cutting speeds of 18 and 33 ft. per min. The motor at 40 h.p. on the high voltage, so that in one case the motor g from 50 to 75 per cent and in the other case from 25 to 35



CURVES SHOWING ELECTRICAL HORSEPOWER AT VARIOUS SPEEDS

of the full load. The teeth for the drive on the chuck were not cut, and the lathe was an old one but in good condition. es show what losses of power may take place in a lathe apparently perfectly satisfactory.

appears from the above that heavy lathes which are re- do both light and heavy turning should have the gear nged so that the full range of speed may be obtained from ltage, and that builders of such heavy machines should total efficiency of the lathe and motor at various speeds s. No engineer would purchase a power-generating plant

without obtaining a guarantee of its efficiency at various loads, and there seems to be no reason why less care should be given to the efficiency of plant using the power. It is true that the expenditure on power is in most cases only a small portion of the total expenditure, but when the total expenditure is large, the small portion becomes quite large enough to trouble about.

31 *Helical Gears.* The gears which are always in mesh should have helical teeth to ensure quiet and smooth running and to prevent chatter. The pinions should be hardened and, of course, all wheels should be made either of forged steel or steel castings.

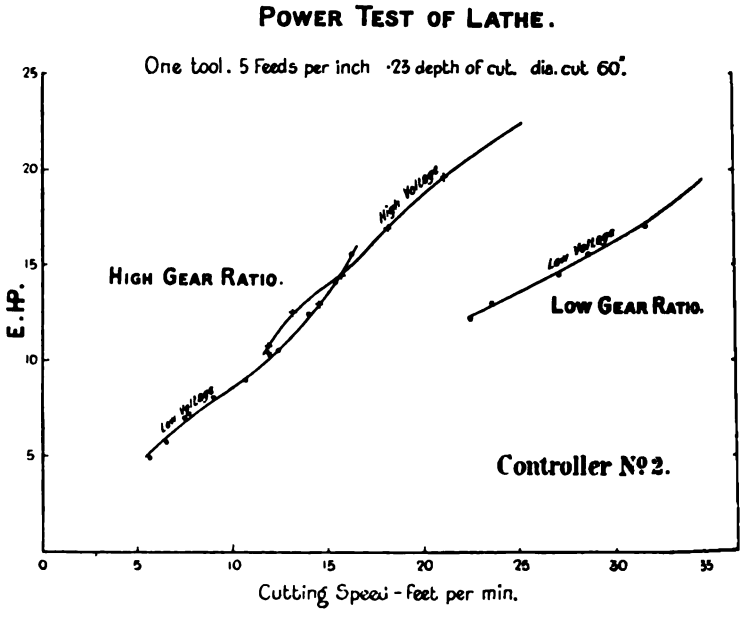


FIG. 6 CURVES SHOWING ELECTRICAL HORSEPOWER AT VARIOUS SPEEDS

32 It is of great importance to cut the teeth of gear wheels to a considerable degree of accuracy. Some idea of what vibration may be set up by inaccurate teeth is given by the following instance. Two teeth having broken out of a gear wheel on a large lathe they were replaced as a temporary measure by pegs filed to shape according to the usual millwright method. The result was apparently satisfactory on low speeds, but a very unpleasant vibration was set up at higher speeds. A diagram plotted from the movement of the ammeter needle, Fig. 7, showed a considerable wave of current at

s. This wave took place after the peg teeth had passed r, and was evidently due to the power required to regain hich had been lost when the peg teeth were in gear. Any- as had to cut gears for motor cars knows how much noise ion may be set up by a very slight inaccuracy in the pitch the teeth.

rm and wormwheels should never be used unless hard- e author has seen the teeth of a cast-iron wormwheel 7 ft. r almost entirely worn away in a few days; the intro-

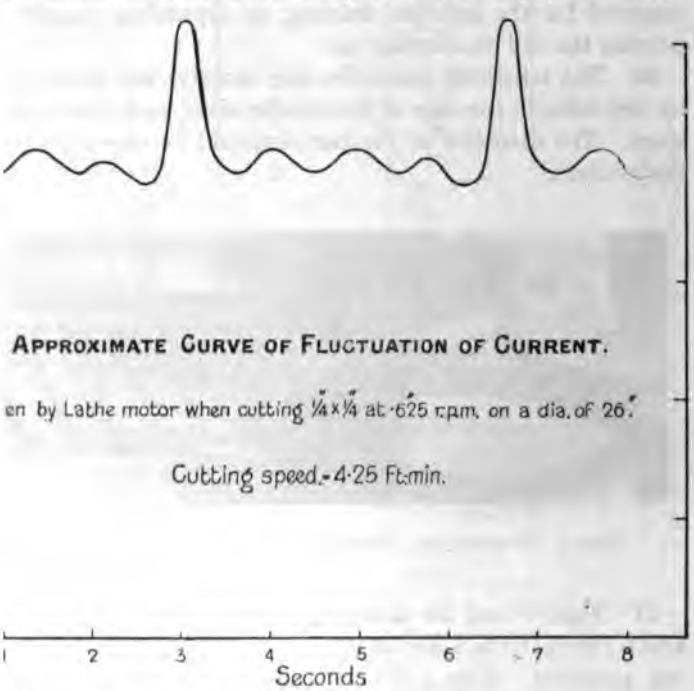


FIG. 7 POWER WAVES DUE TO BAD GEAR-WHEELS

high-speed steel has meant the replacing of many worm wheel drives by spur-gear drives (Fig. 8). All feed its must be amply strong, as in certain cases the side equal to the vertical pressure on the tool.

TYPES OF HIGH-SPEED TOOLS

es especially for Roughing. Very powerful machines are or taking heavy cuts. The beds are made very wide to

give ample support and gearing surface for the saddle, and the spindles are made of what appears to be excessive strength, but it is most important to have ample bearing surface and an absolutely rigid spindle to prevent chatter. A general rule is to make the diameter of the front bearing half the height of the center. Thus a 6-in. center lathe would have a 3-in. front bearing; a 12-in. center lathe would have a 6-in. front bearing; a 14-in. center lathe would have a 7-in. front bearing

35 There should always be a hole through the spindle, as this is required for the bolt for drawing up expanding chucks or for supporting the end of a boring bar.

36 The tailstocks should be very massive and clamped to the bed by two bolts in the case of the smaller sizes, and three bolts for larger sizes. The diameter of the barrel should be one-third the height of the centers.

FIG. 8 WORMWHEEL DESTROYED BY USE OF HIGH-SPEED STEEL

37 Figs. 9 and 10 show plans of a 12½-in. lathe made in 1899, and a 14¼-in. lathe made in 1910 to replace the former lathe for roughing purposes. This lathe was designed for turning nickel-chrome steel and to stand very rough usage, and was therefore made as simple as possible with the further advantage of being inexpensive. The thrust on the spindle was taken up by a ball bearing, one of the tests of the lathe being to screw up the back center with a lever 4 ft. long with a pull of 560 lb. at the end. The driving pulley was turned round by hand with ease when the resulting pressure was on the spindle. Two saddles and three rests are provided, each saddle having its own lead screw, so that one saddle can be run in a different direction and feed to the other. The nuts, 9 in. long, are of cast iron. It is interesting to read in the specification of the lathes built

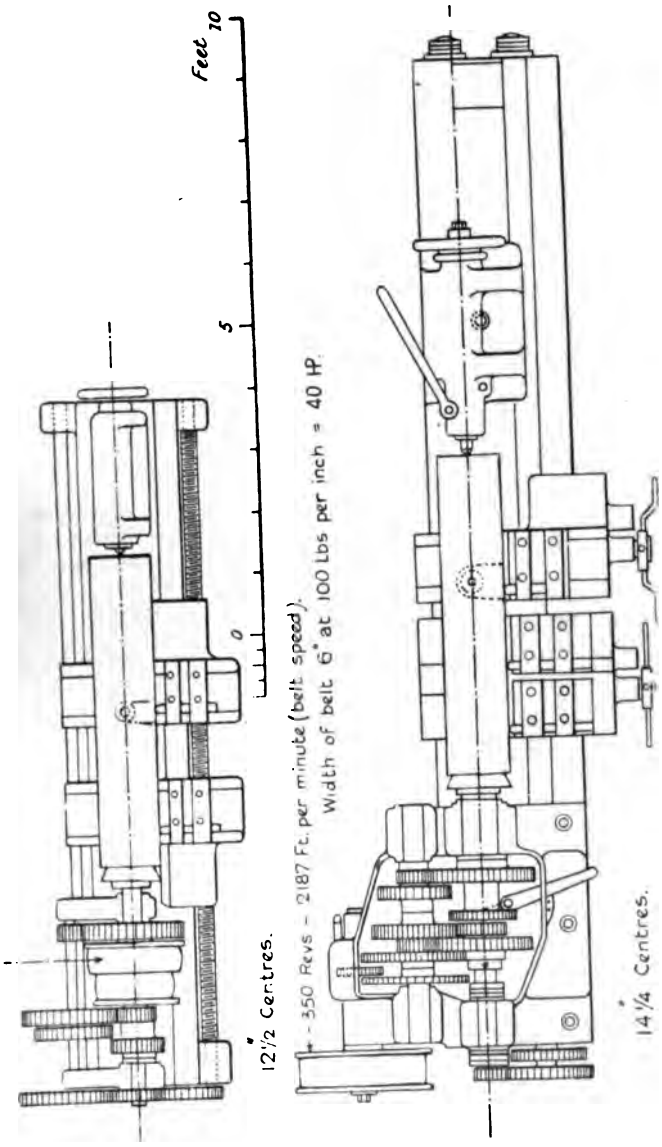


FIG. 9 ROUGHING LATHE BUILT 1899
FIG. 10 ROUGHING LATHE BUILT 1910

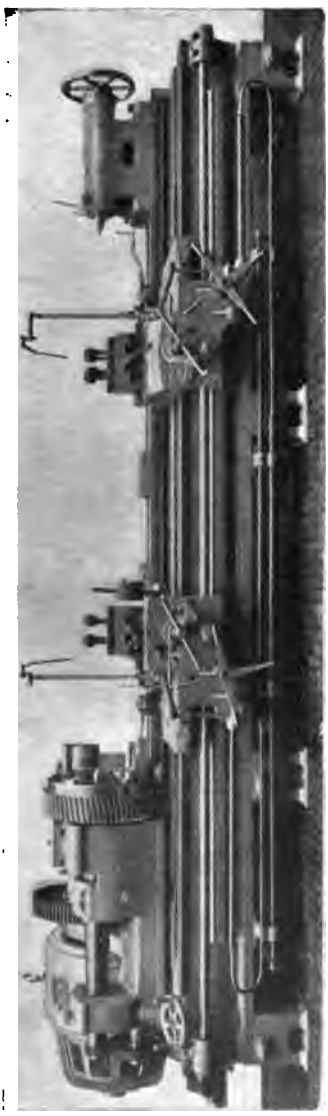


FIG. 11. LATHE FOR TURNING ROADBED AXLES
FIG. 12. HIGH-SPEED LATHE CONVERTED TO HIGH-SPEED

. 1899 that they have been designed on exceptionally powerful ıes to permit of very heavy cuts being taken.

38 Fig. 11 illustrates a lathe for turning straight axles up to 12 . in diameter, and the test cut is two tools, each cut $\frac{3}{8}$ in. deep $_7$. feed at 50 ft. per min. cutting speed, on 35-ton steel, motor 36 h.p.

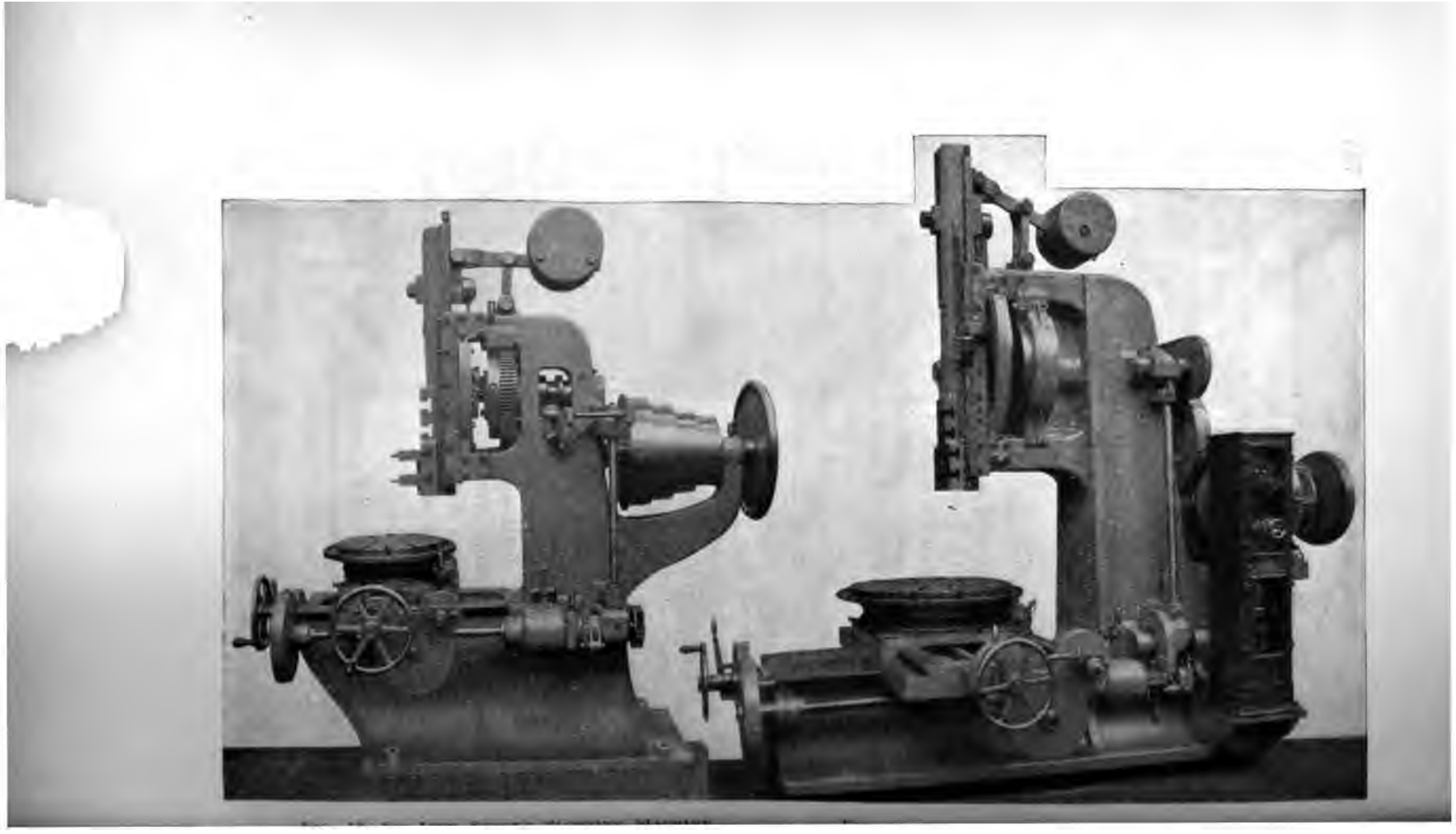
39 One maker of lathes provides an arrangement of expanding ıes with a belt driving by its bevelled edges, and by this means ıy speed between the highest and lowest can be obtained. When ɔplied to a cutting-off machine, arrangements are made so that ıe speed automatically increases as the diameter being cut diminhes.

40 Fig. 12 shows a lathe built in pre-high-speed days converted ɔ cut with high-speed steel; this lathe has since been arranged with direct motor drive. When the author last saw the machine it was ırning bolts 8 in. in diameter, depth of cut $\frac{1}{2}$ in., feed $\frac{1}{32}$ in., cutting ɔeed 300 ft. per min., removing 56 cu. in. of steel per min. A simar lathe was turning a shaft, the depth of cut being $\frac{5}{8}$ in., feed $\frac{1}{8}$ in., nd the cutting speed 80 ft. per min. removing 75 cu. in. of steel per ıin. These are two examples of what may be done with old machines.

41 *Turret Lathes.* Turret lathes have been greatly strengthned, and one capable of dealing with bar up to $2\frac{1}{4}$ in. in diameter an reduce a bar from $2\frac{1}{4}$ in. to 1 in. in diameter at a traverse of $11\frac{3}{8}$ n. per min. with an expenditure of 20.7 h.p., when using the latest orm of high-speed tool steel (*Class C*). The ordinary steadies were ound quite useless at this high duty, and a roller steady has been ntroduced with excellent results. Such a machine fitted with a oller steady averages an output at least 33 per cent greater than the ıtput of the older machines designed for the use of ordinary high-peed steel, and at least 100 per cent more than the pre-high-speed ool machines, so that the extra cost of the modern machines is small ompared to the saving. Of course, such cuts as given above are ot often required, so that a provision of 10 h.p. is quite sufficient or all ordinary purposes. Taking the production from one of these nachines built in 1900 as the unit (see Appendix, Table 4), the folowing figures are obtained:

	£	*s.*	*d.*
1900 machine cost per unit of production...	112	10	0
1905 machine cost per unit of production....	83	12	0
1910 machine cost per unit of production....	71	4	0

42 These figures would vary with the class of work; on some vork the gain would be more, on other work less. This case has



n fully dealt with, as some doubt has been expressed as to the antages of the use of high-speed tools in turret lathes.

3 *Slotting Machines.* Little attention has been called to the ptation of slotting machines for the use of high-speed steel, so a ewhat full description of two machines of quite modern design given, Figs. 13 and 14, the one a 6-in. stroke belt-driven machine, other a 10-in. stroke variable-speed motor-driven machine. The i is carefully balanced and the crank is supported in a bearing at outside end to prevent any side play. The ram is adjusted for ht by means of a worm and pinion which swings into gear by ring a pin. The back of the ram and the plate carrying the con-ting-link pin are serrated to prevent any chance of the ram slip-g. Special attention is drawn to the feed gear, which, in the case the 10-in. machine, consists of a revolving vertical shaft driven n the upper portion of the machine which drives by means of el gears a cam on a horizontal shaft. This cam works a ratchet ch acts on a ratchet wheel provided with a brake to prevent over ning. The whole of this feed gear can be thrown out of action n it is desired to feed by hand. The feeds to the table are put nd out of action by hand levers, and the worm for the circular l can be lifted out of gear, enabling the table to be spun round kly by hand. The feed gear for the 6-in. machine is worked by m on the driving spindle. This cam can be thrown out of action n it is desired to feed by hand, so that all the feed gear is sta-ary.

4 The cutting powers on steel are shown in Table 3. These e taken without the least sign of jar or vibration.

TABLE 3 CUTTING POWERS ON STEEL

se of hine, in.	Strokes, per Min.	Cut in Inches		Feed	Superficial Area Covered Per Min., sq. in.	Material Removed per Min., lb.
		Length	Depth			
10	45	10	$\frac{1}{4}$	$\frac{1}{20}$	22.5	4
6	65	6	$\frac{1}{4}$	$\frac{1}{20}$	19.5	2

5 *Jib Drilling Machines.* Great attention is now paid to mak- these machines so stiff that very little deflection of the saddle es place. One maker provides a double-girder jib with a space between the two girders for the saddle. The saddle is supported

by the girders on each side of the spindle, so that there is no twisting movement round the horizontal axis of the jib. Change-speed gear boxes or variable-speed motors are generally provided, allowing from 12 to 15 h.p. for the larger sizes. Such machines are capable of drilling inch holes at a rate of travel of 5 in. per min., and to drill 100 in. holes in an hour through plates an inch in thickness is ordinary practice.

46 Really fast drilling cannot be done on old jib-drilling machines, as the jibs spring and twist causing the drills to break, and in many cases the arrangement for feeding and withdrawing the spindle are most unsatisfactory, but still high-speed drills can be used to considerable advantage in some of the best makes of pre-high-speed drilling machines by increasing the belt speed. But running the drill at a high speed and a fine feed entails considerable loss of power.

47 *Milling Machines.* The power allowed for milling machines has been greatly increased within the last few years, but it is very doubtful if milling machines should be used, except in special cases, for heavy roughing work, as the power required to remove material with a milling cutter is very large as compared to tools of the lathe type. The milling cutter may be compared to a lathe tool with a very long cutting edge removing a thin wide chip, which, as has already been seen, requires far more power than a tool with a short cutting edge removing a thin narrow chip. The actual consumption of power to remove a pound of material with a milling cutter is about double that required by a lathe tool.

48 *Planing Machines.* A great advance has been made in the cutting speed of planing machines, and naturally with the increase in cutting speed came a desire for a quicker return stroke. Heavy planing machines now have a return stroke speed of 90 ft. per min. and lighter machines are made with a return stroke up to 180 ft. per min., the shock at the reverse being absorbed by recoil springs. Various devices are now made which can be fitted to pre-high-speed planing machines by means of which the above results may be obtained at a moderate expenditure of money, and the results are most satisfactory. It seems a pity that more use has not been made of the arrangement fitted to the planing machines designed by Sir Joseph Whitworth for cutting on both strokes; certainly for roughing out this is very economical.

APPENDIX NO. 1

BLE 4 DETAILS OF HIGH-SPEED STEELS. TWIST DRILLS

Ordinary Grades of Mild Steel and Cast-Iron, using *Class A* High-Speed Steel and Ordinary Tool Steel

Twist-Drills	Size of Drill, In.	Cutting Speed, Ft. per Min.	R.p.m.	Feed per Revolution	Feet in In. per Mm.
.....	½	95	720	0.0097	7
.....	¼	42	320	0.0062	2
.....	¾	100	510	0.0111	5.65
.....	¾	40.5	205	0.008	1.64
.....	1	104	400	0.0125	5
.....	1	38	145	0.01	1.45
.....	1¼	98	250	0.014	3.5
.....	1¼	27.5	70	0.0119	0.84
.....	3	95	120	0.0166	2.0
.....	3	27.5	35	0.0127	0.445

life of the drill would be 50 per cent longer at the same speeds and feeds.
life of the drill would be 100 per cent longer at the same feeds and speeds.

ARTICULARS OF CUTTING WITH TURNING TOOLS OF CLASS B STEELS

Material	Cutting speed, Ft. per Min.	Feeds per In.	Depth of Cut, In.	Material removed, Lb. per Min.	Time Cutting in Min. before the Tool gave out
. 6, Mn. 64.....	80	12	1/16	1.2	169
ilway Tires.....	45	6	¾	9.3	2 tools finished 10 pairs of tires
st-iron Cutting on	70	8	¼	3.6	75
. 24, Mn. 54.....	50	6	1¼	42	128
	Limit of drive				
Tensile.....	250	40	⅛	10.4	Same tool used for three tests. Final condition good.
Tensile.....	300	40	¼	6.3	
Tensile.....	300	40	⅛	10.5	
Tensile.....	300	32	⅛	15.6	.....
e.....	16	4	¼	7½ tons in 82 hr.	82 hr.

TABLE 6 MILLING CUTTERS

Class A for Cutting the Mild Steel; *Class B* for Cutting the Semi-Hard

Material	Size of Cutter	Cutting Speed, Ft. per Min.	Feed, In. per Min.	Depth of Cut In.
Mild Steel	9 in. diameter by 22 in. long	118	2.5	1
Mild Steel	8 in. diameter by 8 in. long	65	10.3	½
Mild Steel		65	5.2	¼
Mild Steel		65	4.25	1
Semi-hard	3 in. diameter by ¾ in. long	75	7	½
Semi-hard	4½ in. diameter by 10 in. long	94	4	⅛

TABLE 7 DIMENSIONS OF PRE-HIGH-SPEED LATHES

Height of centre, in	42	36	21	14	8	6
Width of Belt, in	6	5½	4½	3½	2½	1¾
Front Bearing Diameter, in	13	10½	6	4	2½	1¾
Front Bearing Length, in	21	16½	9	7	3½	1¾
Tailstock Barrel Diameter, in.	8½	7½	4½	3	1¾	1¼
Stepped Cone Largest Diameter, in	41	36	21½	18	11½	8¼
Stepped Cone Smallest diameter, in	20	16	12½	9	4½	4
Revolutions of Countershaft	130	130	104	88	196	160
Horsepower from Fastest Belt Speed	25	20.3	6.2	3.55	1.44	0.56
Horsepower from Slowest Belt Speed	12.4	9.2	3.75	1.77	0.58	0.25
Calculated on Lb. per In. of Width	100	100	80	80	40	40

TABLE 8 THREE TURRET LATHES, COMPARISON OF COSTS

Date	Price of Machine		Per Year Machine Charges at 10 per cent	Per Unit of Production	Cost of Wages 2500 Hr. at 7d. Hr.		Cost of Tool Steel for 2500 Hr. 2 Lb. per 50 Hr.		Cost per Year, Wages and Steel		Floor Space, Roof, etc., at £6 per Sq. Yd.		Charges Floor Space at 10 per cent		H.p. in Proportion to Production at 1d. per h. p.-hr.	H.p. per Unit of Production	Grand Total. Wages, Tool-Steel Charges and Power	
	Total	Per Unit of Production			For Year	Per Unit of Production	For Year	Per Unit of Production	For Year	Per Unit of Production	Total	Per Unit of Production	For Year	Per Unit			For Year	Per Unit
	£	£ s.	£ s.	£ s.	£	£ s.	£ s.	£ s.	£ s	£ s.	£	£	£ s.	£ s.	£ s.	£ s.	£ s.	£ s.
1900	230	230 0	23 0	23 0	73	73 0	2 10 at 6d.	2 10	75 10	75 10	36	36	3 12	3 12	10 8	10 8	112 10	112 10
1905	270	180 0	27 0	18 0	73	48 13	6 5 at ½	4 3	79 5	52 16	36	24	3 12	2 8	15 12	10 8	125 9	83 12
1910	325	162 10	32 10	16 5	73	36 10	12 10 at ¾	6 5	85 10	42 15	36	18	3 12	1 16	20 16	10 8	142 8	17 4

Production: 1900 Machine, 1.0; 1905 Machine, 1.5; 1910 Machine, 2.0

No. 1291*b*

'ICAL DISCUSSION ON HIGH-SPEED TOOLS

llowing the paper on High-Speed Tools and Machines to Fit ı, presented by H. I. Brackenbury at the meeting in Birming- England, was a topical discussion[1] on high-speed tools written contributions by John Calder, Luther D. Burlingame L. P. Alford, Members of the Society. These contributions a resumé of American practice and outputs in rapid machine- work and lantern slides were displayed by the first two authors ıng modern American tools and examples of work produced by . These introductory discussions were followed by a general ssion from the floor.

RAPID PRODUCTION IN MACHINE WORK

Discussion by John Calder

ıong the heaviest work in metal turning is that of railroad tire ng. The capacity of the latest heavy motor-driven driving- l lathes is remarkable. Test runs show the possibility of an ıt of 10 to 14 pairs of driving wheels in a day and the Niles- ·nt-Pond Company report the average capacity of their extra- · lathes in four of the best-known railroad shops to be eight pairs ving wheels in 10 hours, and of what is called their "Standard" ıg-wheel lathe five or six pairs of wheels in 10 hours.

inquiry has been made by the Railway Age Gazette of New as to the output of the principal machine tools in locomotive · shops, with a request for information on work performed · normal conditions during 10-hour periods and the report of ıvestigation is given in the issue of this journal for February .0.

s discussion is here published in abstract only. The complete discus- gether with engravings made from the lantern slides appeared in the t of the Meeting in England published in *London Engineering*, August 5,

The report on turning worn driving-wheel tires is from shops using lathes built between 1901 and 1909, three lathes being of the latest type and ten of earlier types. The majority of the records relate to tires averaging 62 in. in diameter and show that a majority of the shops are turning the equivalent of five pairs of 62-in. tires in ten hours, the highest record being eight and the lowest three.

Tire-boring is not such heavy work as the tires are rolled close to finished size. A large number can be bored per day, but this work as carried on in different shops shows a wide variation of from six or eight to forty or forty-five tires in 10 hours. An output of thirty to forty tires per day would be good practice.

The records show that from two to four cast-iron centers can be finished per day and that one to two and one-half steel centers represent average work.

The records for turning locomotive axles are from twelve shops which rank among the best in the country, and include one which reports 4 steel axles 9 in. in diameter, one $3\frac{1}{2}$ axles 9 in. in diameter, two 3 axles 8 in. and 9 in. in diameter, one $4\frac{1}{2}$ iron axles $7\frac{1}{4}$ in. in diameter. Four shops report only one steel axle in ten hours and some others report only two. Many repair shops use for axle turning an ordinary lathe with narrow belt built years ago. Special lathes for locomotive axles built in recent years have a $5\frac{1}{2}$-in. belt, or if direct-connected, a 25-h.p. motor. The reports on axle turning show that about 50 per cent of the shops are up to the mark set as a suitable capacity for the new type of tools, the output of which should be from three to five axles with $9\frac{1}{2}$ or 10-in. journals in 10 hours.

CAR-WHEEL TURNING

The plants of the Niles-Bement-Pond Company have built car-wheel lathes of different types for many years and the records of this company indicate that the improvement in tools and steels, in the lathes themselves and in the methods of handling the work have increased the output of wheels three-fold during the past ten years in the best equipped shops. Ten years ago 6 pairs a day was considered a fair output; five years ago 12 pairs a day; and now many railroads are equipped with lathes turning out from 16 to 20 pairs of 36-in. wheels in ten hours.

The most recent record is from tests made on a Pond 42-in. motor-driven car-wheel lathe at the West Albany shops of the New York Central Railroad. Both Krupp and Paige wheels were turned and

tools were of Mushet high-speed steel. The record is 25 pairs 36-in. wheels in 7 hours and 54 minutes with one operator and one per; average time for turning 19 minutes. The operations were ided as follows:

Average time putting wheels on lathe....2 minutes, 53 seconds
Average iime roughing.....9 minutes, 26 seconds
Average time finishing.....5 minutes, 24 seconds
Average time taking wheels out of lathe..1 minute, 17 seconds
Average depth of cut, $\frac{5}{16}$ in.; feed, $\frac{1}{32}$ in.; speed 16 ft. per min.

In turning, the tool is driven directly under the hard skin caused the friction of the brake shoes upon the wheels and a roughing taken across the tread. After that a finishing tool, the shape and width of the tread, is fed directly in without any cross feed and ally a forming tool is used to give the shape to the flanges.

MANUFACTURING LATHE

Recent improvements in machine tools have been in the direction reducing the idle time between cuts so that the cutting tool may in nearly constant operation and the full capacity of the machine lized.

A manufacturing lathe manufactured by the Lodge & Shipley Mane Tool Company is designed with a multiple stop attachment for longitudinal and cross feeds, whereby all measurements after first setting of the tool are obtained mechanically. The location the shoulders on the part being turned is controlled by adjustable ps which can be set in the desired positions on a bar beneath the on, and thereby throw out the power feed at these points and allow carriage to be brought up by hand against a positive stop. There also adjustable stops for locating the cross slides to determine responding diameters. The lathe has a compound rest for turnand a rear plain rest carrying an inverted squaring or necking l. These two rests are connected and as soon as the longitudinal l trips automatically, determining the position of a shoulder, the ire cross slide is fed forward. This withdraws the front tool from cut and the rear tool squares the shoulder and necks the piece is subsequently to be ground. If large numbers of pieces are to made, a spacing bar containing notches for tripping the feed is d in place of the stops.

Examples of work are shown in Fig. 15. The upper piece is a chinery steel change-gear shaft for an 18-in. lathe. Comparative

tests were run by the same operator with two groups of six shafts each. Using the best engine-lathe methods with hand calipering, the time for the six was 96 minutes with limits allowed of ± 0.003 in. With the multiple stops the time was 66 minutes and sizes were within 0.001 in. The other piece of work illustrated in Fig. 15 is an armature shaft of 0.50 carbon steel turned at a surface speed of 160 ft. per min. with a feed of 75 per in. The piece had to be reversed in the lathe in order to get at both ends. Two chips were taken over the small diameters at the ends and one over the center of the shaft, leaving 0.012 in. for grinding. The turning time, including handling, was 21 minutes.

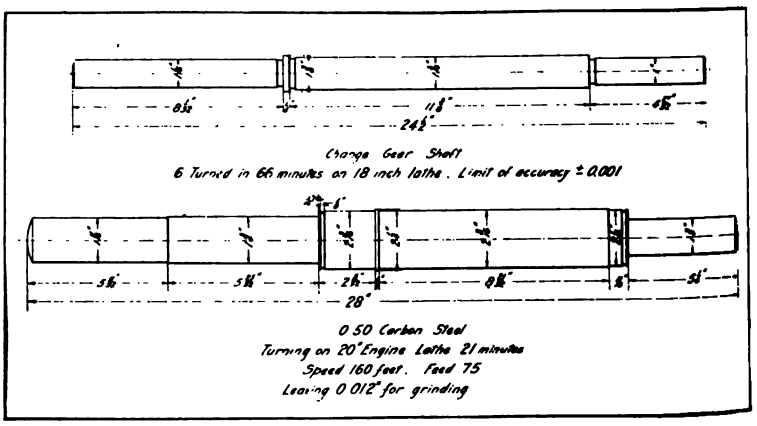


FIG. 15 EXAMPLES OF WORK DONE ON A MANUFACTURING LATHE

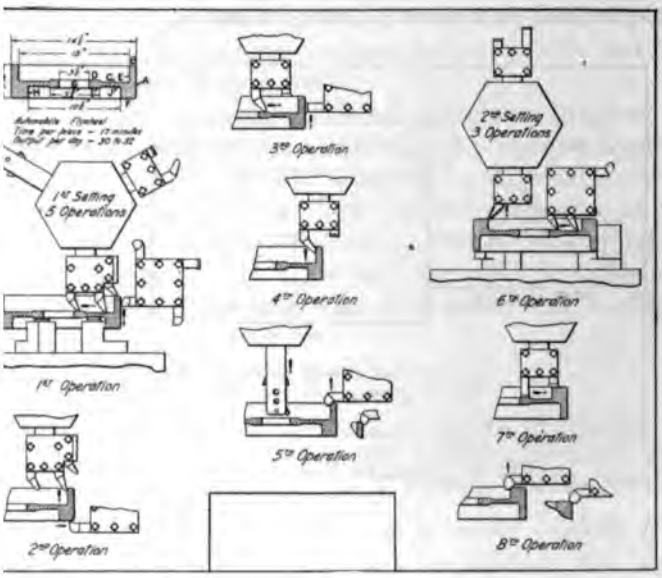
As another instance of the effort to economize time between the actual periods of cutting examples were referred to of pieces machined in the Bullard Vertical Turret Lathe. The tool equipment and successive operations in machining an automobile flywheel are shown in Fig. 16.

MILLING

Here the speaker quoted results given in a paper upon The Development of a High-Speed Milling Cutter by Wilfred Lewis and William H. Taylor, (the Taylor-Newbold cutter being referred to), published in Volume 30 of Transactions of The American Society of Mechanical Engineers. Reference was also made to extremely heavy milling performed at the American Locomotive Company's works at Dunkirk, N. Y. on a Bement rod-milling machine, 48 in. between housings, equipped with a 62-h.p. motor. During tests this machine has re-

arly 23 lb. of metal per minute, or at the rate of 1380 lb. but the motor was then greatly overloaded. To remove 1200 lb. per hour would require a 90-h.p. motor. A practng capacity is stated to be 672 lb. of metal per hour. The d inserted blades of high-speed steel.

her illustrative of the tendency to reduce the waste time for and adjusting the machine in machining operations as well ire the most economical speeds and feeds for a given piece



PERATIONS IN MACHINING AN AUTOMOBILE FLYWHEEL ON A VERTICAL TURRET LATHE

s the method followed by the Cincinnati Milling Machine of issuing instruction sheets to accompany the work. This operations, tools to be used, and time in which the work mpleted—the "Standard" time. The work is done on the system, based on a "Premium" time; but if completed e standard time a bonus also is paid.

GEAR CUTTING

les of gear cutting on Gould and Eberhardt machines were s follows: A 90-tooth cast-iron gear, 3-in. circular pitch,

nearly 88 in. outside diameter and 12-in. face. This was blocked out on a Gould and Eberhardt 84 in. by 16 in. gear-cutting machine in 2 hours and 20 minutes with a gang of three carbon steel cutters, at a feed of 11 in. per min.

A 122-tooth cast-iron gear, $1\frac{1}{2}$ diametral pitch, approximately 82 in. in outside diameter and 6-in. face. Blocked out with a "Novo" steel cutter at a cutting speed of 65 ft. and a feed of 10 in. per minute; time 1 hour and 50 minutes. Teeth were finished with a carbon steel cutter at a speed of 52 ft. and a feed of 7 in. per min.; total cutting time for both operations 4 hours 8 minutes.

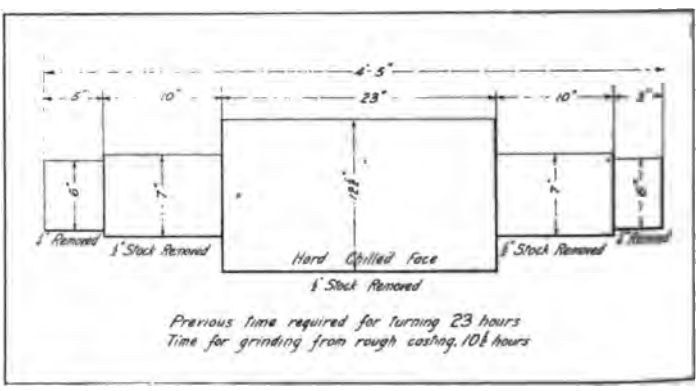


FIG. 17 CHILLED ROLL FINISHED BY GRINDING

A 20-tooth pinion of open-hearth steel, 3-in. circular pitch, 12-in. face, one roughing and two finishing cuts with carbon steel cutters feed 1.3 in.; total time $10\frac{1}{2}$ hours.

By contrast in point of size were pinions generated on a Gleason 6-in. bevel-gear generating machine in the Brown-Lipe Gear Company's works, Rochester, N. Y. A $\frac{5}{7}$-diametral pitch steel pinion, 10 teeth $\frac{7}{8}$-in. face, was finished, after first roughing out, in 1 minute 15 seconds. This does not include time for adjusting the machine or blank. The builders, however, recommend 100 seconds as the cutting time for pinions of this size.

CYLINDRICAL GRINDING

Under the present advanced state of the art of grinding the abrasive wheel is taking its place with the lathe or planer tool and the milling cutter, as an efficient tool for operating directly on rough casting

forgings from which as much as ½ in. of metal (on the diameter) have to be removed in extreme cases or for finishing surfaces which a single roughing cut has been taken with a coarse feed, ng, perhaps $\frac{1}{32}$ in. of metal to be removed.

ı interesting example of this is the grinding of chilled-iron car els. During a test made at the Pennsylvania Railroad shops at ona, Pa., on a machine built by the Norton Grinding Company, cester, Mass., 106 pairs of wheels were ground in 27 hours 20 ıtes, or at an average of 15½ minutes per pair. Of these wheels, airs were new, one pair was of steel and the rest we e flat wheels, it may be noted that the time compares favorably with that for ing steel-tired wheels in the lathe.

ıilled rolls are also successfully finished entirely by grinding in sive machines without previous turning. An example typical any, Fig. 17, is of a roll 4 ft. 5 in. long, 12½ in. largest diameter, several shoulders and ½ in. of stock (on the diameter) to be n off, which was ground in 10½ hours. The previous turning had been 23 hours. The wheel used was a No. 24 Alundum el—that is, 24 grains to the inch—one grade softer than medium.

SURFACE GRINDING

he grinding of plane surfaces instead of milling or planing is ılarly done on a vertical surface grinder made by the Pratt and tney Company. The machine has a vertical spindle with a ical feed, carrying a cupped grinding wheel. The work is held, erably by a magnetic chuck, on a work table, either reciprocating otating as desired. Examples of such work are square trans- sion shafts for automobiles, ground from the rough bar at the of three or four an hour; piston rings 7 in., 9 in. and 11 in. in neter, ground from the rough at the rate of 40, 50 and 60 an hour ıectively; aluminum and iron castings for automobiles, etc., gh cast surfaces, ground at the rate of 12 to 40 pieces an hour.

DATA ON MANUFACTURING METHODS WITH MACHINE TOOLS

Discussion by Luther D. Burlingame

'he extensive set of special tools required to make a modern 'hine tool on a manufacturing basis and to attain the degree of ıracy required is indicated by the tool equipment for making the

spiral head swivel for a universal milling machine. The 18 special tools required for making it are listed below:

a Boring fixture and tools in cupboard; *b* apparatus for grinding; *c* driver for turning; *d* counterbore for spindle rear washer seat *e* jig for drilling front bushing screw holes; *f* reamer for index stop pi hole; *g* taper reamer and test plug; *h* roughing and finishing tap reamer; *i* arbor for turning; *j* jig for drilling wormshaft bushing, sto screw hole; *k* jig for drilling oil and screw holes; *l* jig for finishin

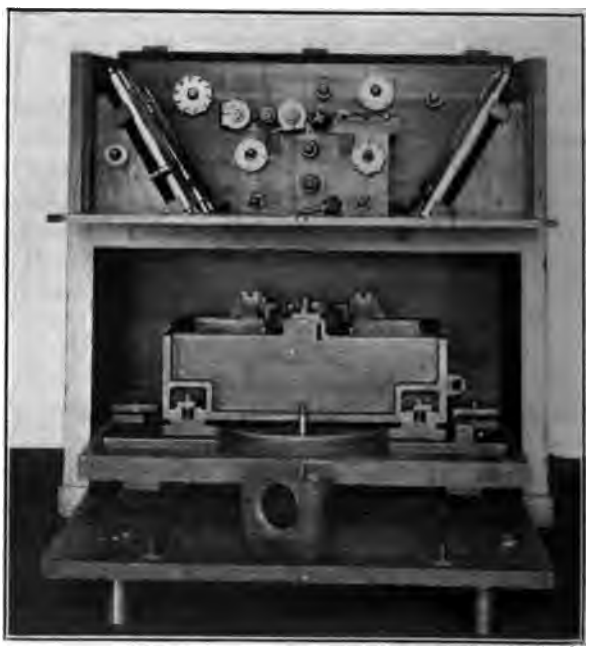


FIG. 18 BORING FIXTURE FOR SPIRAL HEAD SWIVEL

drilling spindle stop pin hole; *m* milling cutter; *n* fixture for gra ating; *o* fixture for testing graduations; *p* test plug; *q* bushing testing rear bearing; *r* device for testing.

Among these tools the fixture for boring has been selected as t ical of the extent of equipment necessary for the production of s parts. Fig. 18 shows this fixture in the cupboard made to store when not in use and in the front is a spiral head swivel for the ma facture of which the fixture was designed. The boring bars and c ting tools have their proper place in the top section of the cupbo

g so grouped that the tools for use in each position are together. fixture itself is placed on a carriage in the lower part, this car- e being mounted on wheels which are guided on a track. When ront door is opened a section of track attached to it and matching rack in the cupboard provides so that the carriage can be drawn to a position where it can be readily lifted onto the boring mill. ook on the end of each rail prevents the carriage being run off the floor. This boring fixture is of special interest in that it can et to bore the swivel in three positions without removing it from ixture.

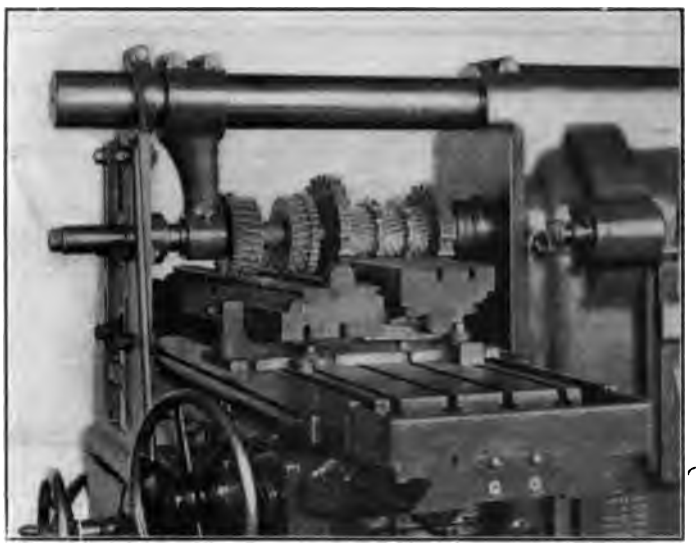


FIG. 19 MILLING TOP AND BOTTOM OF MILLING MACHINE TABLE

illing Top and Bottom of Milling Machine Tables. Fig. 19 is an mple of milling in which the top of one table and bottom of another e of a universal milling-machine are milled at one traverse of the hine, the milling being done on a Brown and Sharpe No. 5-B y plain milling machine. At the completion of the cut one table moved and the other one, which has been milled on the top only, rned over, so that the bottom may be milled, while a rough cast- s put in its place and the cut repeated. This illustrates economy andling the work as well as in the time of milling. The large

cutters are of high-speed steel, the small cutters, running at much lower surface speed, are of ordinary carbon steel.

An Example of Heavy Milling. An example of heavy milling on a machine of the same size and type as used for the milling-machine tables is to be had in tests made on a steel block of 65,000 lb. tensile strength. Eighteen cubic inches of metal were removed per minute. The output of the motor was 21.05 h.p., making 0.85 cu. in. removed per net horsepower. At no time during the test did the machine show signs of distress or appear to labor excessively, and the notable absence of vibration was emphasized in the following manner. A coin was placed upon its edge at one end of the table, with its side

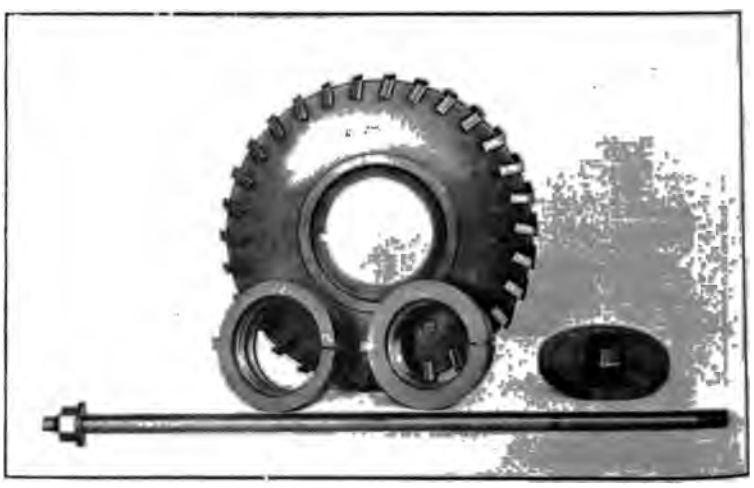


FIG. 20 INSERTED TOOTH CUTTER USED IN MILLING FLAT-IRON BOTTOMS

at right angles to the axis of the table, and on the opposite end a full glass of water was placed. The machine was then started and many cuts taken without overturning the coin or spilling any of the water.

A feature of note in connection with this test is the efficiency of the high-speed steel cutters employed. One gang removed 1800 cu. in. of steel without sharpening. The cutters were so nicked as to produce chips about $\frac{3}{16}$ in. long.

Continuous Milling. An example of continuous milling on a No. 5 vertical spindle milling machine is of ten flat-iron bottoms held in a special fixture on the circular milling attachment. The table

s one complete revolution in four minutes, thus finishing the es of ten flat-irons in four minutes, or 150 per hour. The fix- s so made that the workman can easily replace the work and the machine going continuously. The cut on each piece is 8 in. long and $4\frac{1}{4}$ in. wide at the widest part, and about $\frac{1}{16}$ in.

Fig. 20 shows the style of inserted tooth-cutter used, which is ed to avoid undue projection beyond the end of the spindle,

TABLE 9 RECORD OF GEAR CUTTING RESULTS

16 PITCH CAST IRON GEARS $\frac{3}{4}$" FACE 13,000 LB. TENSILE STRENGTH. CUTTER $2\frac{1}{2}$" DIAMETER 1" HOLE, 15 TEETH.										
Number	1	2		3		4		5		
Kind of Steel for Cutter	Carbon	High Speed		Carbon		High Speed		High Speed		
With or Without Air Blast	Without	Without		With		With		With		
Number of Gears Cut at Once	5	4		4		4		4		
Revolutions Per Minute of Cutter	130	285		180		340		340		
Periphery Speed of Cutter in Feet Per Minute	85	186		118		222		222		
Feed in Inches Per Minute	$5\frac{3}{8}$	15		9		21		18		
Total Face of Gang	4"	$3\frac{3}{16}$"		$3\frac{3}{16}$"		$3\frac{3}{16}$"		$3\frac{3}{16}$"		
Number of Teeth in Gear Being Cut	35	42	48	70	72	78	80	80	84	90
Cutting Time Per Setting in Minutes	32	12.6	15	35	36	18.2	18.6	22.7	23.8	25.5
Number of Teeth Cut Before Resharpening Cutter	3,500	6,684		5,534		12,236		25,502		

w the cutter to be easily removed, and to make it possible to e same cutters on machines with different sizes of spindles.

mercial Gear Cutting. Table 9 gives data for commercial n a Brown and Sharpe No. 3 automatic gear-cutting machine ing 16-pitch cast-iron gears with ordinary carbon steel cutters, peed steel cutters, and with or without an air-blast. The ut when these records were made all passed inspection and were to use.

air-blast adds materially to the rate of production, as will be y comparing the feed in inches per minute of Nos. 1 and 3, a gain of nearly 70 per cent is made when using the air-blast

with carbon cutters and by comparing Nos. 2 and 4, where a gai 40 per cent is made when using the air-blast with high-speed cutt

The high-speed steel cutters with the air-blast give an increas production of almost 4 to 1 over the carbon cutters without the blast. In cutting cast-iron gears of coarser pitches, the gain is al the same proportion. Even under the fastest cuts the gear t show surprisingly little tendency to break out at the back, althc cut without being supported. The air-blast is supplied by a St

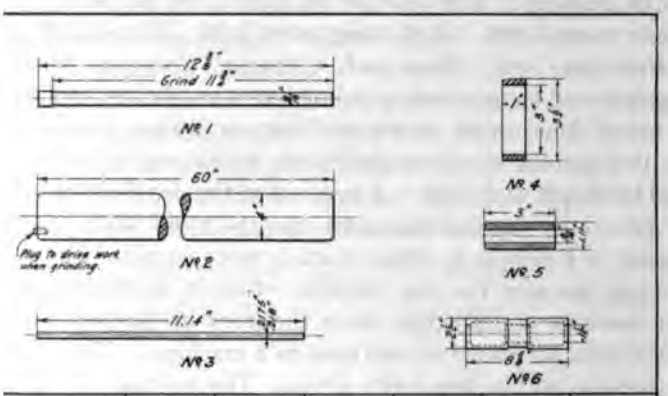
FIG. 21 NEW TYPE OF STOCKING CUTTER

vant blower discharging through a tube 1¼ in. in diameter at a sure of about 1½ oz. per sq. in., this being sufficient to cool the cutt keep the chips away.

The following records are of commercial work done in the ge partment of the Brown and Sharpe Manufacturing Company on 6 automatic gear-cutting machine. In the first example three ing cutters were used in a gang, finishing three teeth at once. second of two methods tried better results were obtained by a stocking and finishing cutter together than by using two fir cutters. Oil was used as a lubricant in both cases. The da these examples are as follows:

ırs of steel castings, 70,000 lb. tensile strength, 3-pitch , 67 teeth. Cutter 6 in. in diameter, $1\frac{3}{4}$ in. hole, 52 r.p.m., rface speed per minute, $2\frac{9}{16}$ in. feed per minute. Feed, per revolution of cutters. The three cutters cut three 67 minutes each, without sharpening the cutters, which ood condition, and could have cut several gears more.

TABLE 10 RECORD OF RESULTS IN GRINDING



umber	1	2	3	4		5	6	
aterial	Soft Machinery Steel	Machinery Steel	Mach. Steel Case Hardened	Mach. Steel Case Hardened		Cast Iron	Bearing Bronze	
Ground	External	External	External	Internal		External	External	
" of Stock d (in Diameter)	.012" Roughing .002" Finishing	.025" Roughing .005" Finishing	.005" Roughing .001" Finishing	.018" to .020"	.010" to .012"	.020" to .025"	.012" to .015"	
ired Limit	Standard .0005" Small	Standard .001" Small	Standard .0005" Small	Std. to .0005" Large	Std. to .0005" Large	Standard .0005" Small	Standard .0005" Small	
r of Pieces ted Per Hour	13	3.5	15	16	20	54	32 1 Man	59 2 Men
Lots of	100	50	500	200		200	100	

ırs of steel castings, very hard, probably 100,000 lb. -in. face, 51 teeth. The cutters, 6 in. in diameter, $1\frac{3}{4}$ in. 51 r.p.m., 45 ft. surface speed per minute, $1\frac{3}{16}$ in. feed per Feed, 0.042 per revolution of cutters. Cutting time,

ughing-cutter used in the second example was a new design d stocking-cutter shown in Fig. 21.

ng out Gear-Teeth The following record was made with

the new design of stocking cutter in roughing-out gear teeth, on a No. 5 automatic gear-cutting machine.

Gear blanks of machinery steel 65,000 lb. tensile strength, 4½ in. in diameter, 6-in. face. Cutter 3-pitch stocking, 5¼ in. diameter, 1½ in. hole, 90 r.p.m., 124 ft. cutting speed per minute, 7 in. feed per minute; feed 0.078 in. per revolution of cutter. Cut 15 teeth, 0.749 in. deep; total number of inches cut, 90. Cutter in good condition at end of cut. Test made with 7½-h.p. motor belted to countershaft of the machine. Efficiency of the motor, 78½ per cent. Gross horsepower used, 5.089. Net horsepower, 3.99, 110 volts, 40 amperes.

Grinding Data, Plain and Universal Grinding Machines. The examples of commercial grinding given in Table 10 illustrate what is being done under actual working conditions in commercial work on the variety of pieces indicated, which are of various materials and both soft and hard. A reversal of the usual rule where economy is gained by having one man operate more than one machine is shown in Example 6, where work is more economically produced by having two men run one machine—that is, having one man operate the machine and a helper drive the work on and off the arbor. All other data are based on one man to a machine. These pieces passed inspection within the limits given. The average loss from work of this class coming below the required limit or being otherwise spoiled is less than ¼ of one per cent.

DEVELOPMENT OF HIGH-SPEED DRILLING MACHINES

DISCUSSION BY L. P. ALFORD

This discussion will be confined to a brief abstract of three articles published during the last few months in the American Machinist,[1] describing machines made by five different firms and records of tests.

In January 1909, the Bickford Drill & Tool Company, Cincinnati, Ohio (since purchased by the Cincinnati Bickford Tool Company), shipped four radial drilling machines, each of which was subjected to the test of driving a 1¼-in. drill in steel at a speed of 310 r.p.m. (101.45 ft.) and 0.038 in. feed. The least power consumed by this

[1]See Radial Drilling Machines and Records, by F. E. Bocorcelski, page 479; Tests of a Remarkable High Speed Radial Drill, by H. M. Norris, page 916; High Power Drilling Machines, page 1189, all of Vol. 33, Pt. 1.

k was 18 h.p. and the maximum 21.3 h.p. Of the half dozen or re of the 1¼-in. drills of various makes submitted for trial, there not one that the machine was not capable of destroying.

rom the experience with these four machines a fifth high-speed ial drill was built and exhibited in June 1909, at the Atlantic City nvention of the Master Car Builders' Association. This machine l a speed range from 38 to 519 r.p.m.; the greatest peripheral gear ed was 960 ft. per min. It has successfully driven a 1¼-in. drill a steel block, stated to be 55-point carbon, at 425 r.p.m. (139 ft.) l 0.02 in. feed, giving a depth of hole drilled per minute of 8.5 without the slightest indication of distress. The machine has ır changes of speed in the head and makes use of but a single luction in driving drills at 100 ft. per min. from ¾ to 2⅝ in. in meter. The gearing is of 3.5 per cent nickle steel hardened.

The following tabulation shows speeds, feeds and depth drilled minute as determined by a demonstration test:

Diameter of Drill	Revolutions per minute	Feet per minute	Feed per revolution	Depth per minute, inches
1	425	111.0	0.020	8.50
1¼	266	104.0	0.020	5.32
2	187	97.9	0.020	3.74
2¼	132	86.4	0.015	1.98
3	107	84.0	0.015	1.61

large number of drilling tests have been made with this machine from these the following tabulation has been compiled showing power consumed per pound per minute of metal removed in driv- a 1¼-in. drill in machinery steel at various speeds and feeds:

Speed		Feed per Revolution in Inches			
evolutions	Feet	0.011	0.015	0.020	0.027
124	40.54	9.49	8.03	6.97	6.28
142	46.45	9.33	8.11	6.96	6.22
170	55.60	8.86	7.62	6.83	6.21
202	66.10	8.43	7.49	6.77	6.21
245	80.19	8.15	7.22	6.61	6.20

his shows that the power per pound of metal removed decreases slowly as the speed is advanced, as compared with the reduction

effected through increasing the feed. Doubling the speed that is running at 245 revolutions instead of the 124 revolutions effects, at the 0.011-in. feed, a saving in power per pound of metal removed of 14.2 per cent, while doubling the feed that is advancing the drill 0.020 in. per revolution, instead of 0.011 in., effects at the speed of 124 revolutions, a saving of 28.7 per cent, or more than two to one.

In regard to cutting speeds these results indicate that drills of the twisted type from 1 to 2 in. in diameter may be operated in steel of 55-point carbon, at a cutting speed of at least 100 ft. and 0.02 in. feed without more than ordinary dulling. There are some steels that can be drilled with safety at 125 ft.

An interesting point is this, a 1¼-in. drill operating at a speed of 100 ft. and 0.020 in. feed requires fewer than 24 sec. to pass through a 2-in. plate. The importance of having a drilling machine that can be easily manipulated is thus forcibly shown, for all of the advantage of high-speed drilling may be lost if too great a length of time is consumed in bringing the head and arm into position for a second hole after the first has been drilled.

TESTS BY THE AMERICAN LOCOMOTIVE COMPANY

In November 1909 and February 1910, tests were conducted by the American Locomotive Company on three high-speed radial drills that had been built to meet the firm's specifications. One each of these drills was made by the Bausch Machine Tool Company, Springfield, Mass., Edwin Harrington Sons' Company, Philadelphia, Pa., and the Niles-Bement-Pond Company, New York. All of these machines proved capable of driving to destruction any drill submitted for test and produced results that we cannot fail to look upon as remarkable.

In all cases the tests were made on special hammered steel billets, the carbon content of which was approximately 0.70 per cent. The Bausch machine drove 1½-in. drills at 290 r.p.m. (113 ft.) and 1¼-in. drills at 330 r.p.m. (107 ft.) with a feed per revolution of 0.0207 in., giving approximately 6 in. of drilled hole per minute; 1⅛, 1⅛ and 1 in. drills were driven at slightly lower speeds and with the same feed. In general the results from the 1¼-in. drills were good, but the 1½-in. drills showed a tendency to dull too quickly or else broke. The horsepower per pound of metal removed per minute for the 1¼-in. drills varied from 10.6 to 14.3.

The Harrington machine drove 1½-in. drills at 284 r.p.m. (110.76

with feeds of 0.025 in. and 0.040 in. corresponding to inches led per minute of 707 and 11.36, respectively. In practically ry case, however, either the drill broke or the electric circuit ned, showing that the capacity of the machine exceeded the capa- ties of the drill.

'he Pond machine drove 1¼-in. drills at 208 r.p.m. (68 ft.) with ed of 0.022 in. per revolution, equivalent to about 6 in. drilled minute with varying results as far as the drills were concerned. ome cases the drills broke; in others holes from 6 to 9 in. deep were led successfully. Drills 1½ in. in diameter were driven at 312 m. (123 ft.) with feeds up to 0.032 in. corresponding with 10.07 drilled per minute with success as far as the machine was concerned. wever, only a few inches could be drilled before the drills failed. ll of the drills referred to in connection with these tests were of flat-twisted type. Both cutting oil containing approximately per cent of lard oil and cutting compounds were used. The latter ve the better results.

The author of the article describing these tests, when summing up best speeds and feeds for active service states: "For maximum oduction and considering the life of drills at the same time, it seems st to run a 1-in. drill about 300 r.p.m. (79 ft.) with a feed of 015 in. per revolution; 1½-in. drills at 225 r.p.m. (88 ft.) at a feed 0.02 in. per revolution."

PERFORMANCE OF COLBURN UPRIGHT DRILL

Within the last few weeks the Colburn Machine Tool Company, anklin, Pa., has brought out a new drilling machine of the upright pillar type. The spindle is 2½ in. in diameter in the sleeve, and a nose 3 11/16 in. in diameter. The spindle speeds vary from 45 to r.p.m. It has a power feed of 16 in. and the table has a vertical ustment of 15 in. It is driven by a 25-h.p. motor.

The feeds are in geometrical progression from 0.009 to 0.06 in. revolution of the spindle.

Tests were made with Celfor high-speed twisted drills in cast iron. ese show that cutting speeds as high as 200 ft. per min. with a d per revolution of 0.06 in. can be used. Drills up to 1½ in. diameter were driven at a speed of 520 r.p.m. with a feed per olution of 0.060, corresponding to 31.2 in. drilled per minute, l uniformly the drills were in good condition after having passed ough a 4-in. block. These test blocks are of cast iron of the fol-

lowing representative analysis: silicon 2.94, manganese 0.60, gr
ite carbon 3.17, combined carbon 0.15, phosphorus 0.446, sul
0.08.

In a few tests on steel that were reported, $1\frac{1}{4}$-in. drills were dr
at cutting speeds of 120 ft. per min. and feeds, giving inches dr
per minute, from 7 to 10.4. Similarly $1\frac{1}{2}$-in. drills were driven
cutting speed of 102 ft., $1\frac{3}{4}$-in. drills at 86 ft. and 3-in. drills at 7
with feeds varying from 2.8 to 10.7 in. per min.

No. 1291*d*

DISCUSSION ON HIGH-SPEED TOOLS

THE CHAIRMAN (Dr. Goss)[1] said it had been suggested to him that should announce that twenty-five different builders of American achine tools had made formal contributions to the topical dis-ssion which had just been presented, and without desiring to tract for a moment from the work of the authors of the papers, he shed to say that the contributions of the American machine tool ilders had contributed to the success of the meeting.

J. HARTLEY WICKSTEED[2] said that, on the sandwiching prin-ple, he proposed to go back to Mr. Brackenbury's paper, and after had spoken no doubt further remarks would be made on the con-butions which had just been read. In the very last sentence of Mr. ackenbury's paper attention was called to the neglect of the uble-cutting principle in planing machines, which had been shown engineers genera'ly. In that remark he very heartily concurred. ore than fifty years ago Sir Joseph Whitworth showed his appre-iation of the principle of double cutting, by devising a tool box ich cut on both strokes. The tool turned halfway round at each l, and therefore was facing the work to cut either backwards or wards. That tool box of Sir Joseph Whitworth's had been used r since, and was largely used for the work of plate-edge planing. supposed that all the ship plates and girder plates that had been de in England had been planed on both strokes, and he thought t since the invention of that simple tool holder nobody had been ficiently uneconomic to use an idle stroke on a plate-edge plan-; machine. Other people tried to improve upon Sir Joseph Whit-

Mem.Am.Soc.M.E.

M.I.Mech.E., Messrs. Joshua Buckton & Co., Well House Foundry, Meadow , Leeds, Eng.

Presented at the meeting of THE AMERICAN SOCIETY OF MECHANICAL GINEERS with THE INSTITUTION OF MECHANICAL ENGINEERS, Birmingham, gland, July 1910.

worth's turn-round tool box—to make a good double-cutting tool box with back-to-back tools capable of traversing over surfaces of material, capable of having a proper angle given to the cutting edge of the tool, and capable of being used on emergency on one stroke only; as, for instance, when one had to plane up to a narrow landing and had no room either to turn a tool round or to overrun the distance between the two tool points; or when one had to plane points and crossings, where it was obviously impossible to meet the fine knife edge of the switch with a heavy cut, and one was compelled to plane in one direction only. But the makers who followed Sir Joseph Whitworth with that attempted development of his principle did not succeed all at once in making the double-cutting tool box equally as strong, for taking a cut, as the ordinary flapper single tool box. Therefore the growth of double cutting had been a slow growth.

There were inherent advantages in double cutting which must force themselves upon the attention of engineers in the course of time, and he would mention three of those advantages which he did not think were generally grasped. In cutting large surfaces of cast iron with a number of slot holes or edges the tool had to encounter hard scale. The harder cast-iron was made, the harder the scale was apt to be in proportion. In cutting over such surfaces with two back-to-back tools, the forward cutting tool whenever it came to the edge of the slot hole and other edges chipped away a small particle of scale. The backward cutting tool entered clean metal therefore, and in its turn chipped away a small particle of scale for the forward cutting tool in its turn to enter clean metal. The consequence was that, in taking a rough cut over a casting with sand and scabs and chilled scale upon it, the result of the first cut was as good as the result of the second cut would be if one tool was not relieved by its companion tool. The second cut had nothing to do except to true up the work after it had been relieved of constraint by the removal of the skin. Of course after the first skin had been removed they must have a second cut to rectify the recovery of the internal stresses before the scraping cut was used. One of the advantages, then, of the double-cutting principle was that a roughing cut was obtained infinitely more uniform than could be obtained with a single tool, partly because of what he had stated about clearing away the scale and partly because the cut was divided between two tools. Therefore with a large surface, such a surface as a 30 ft. by 12 ft. planing machine table full of slot holes, it was possible to go over the whole surface without removing the tool for regrinding, because each

l had done only half the surface, the other tool having done the er half. Each tool had relieved the other in the way he had already lained.

There was also an advantage in having a machine that had not a ck return stroke, but that was able even if cutting only upon stroke, to take that stroke in either direction, because it had n found that when cutting with a parting tool the back cutting l used a straight parting cutter, whereas the front cutting tool st have an expensive parting cutter with more overhang in order allow of its being cranked back to prevent it digging into the rk, whereas a straight cutter put into the back tool would relieve lf sufficiently to make no chattering in the bottom of the parting ove. The same remark applied to a scraping cutter. With a ad scraping cutter fewer chattering marks were obtained if the tters were put into the back holder, than if they were put into the nt. Some of those advantages were slowly dawning upon users large machines, and he did not think that anybody who took the ghtest care in thinking what he was going to do would put down planing machine, for instance, for planing turbine cases which ght be 20 ft. wide and 50 ft. long, that did not cut both ways, cause he could plane his turbine cases better and cheaper as regards e machine and very much cheaper as regards the power that was nsumed. He also thought people were getting a little educated driving machines with motors for which they sometimes had to y a penny a unit for power, and never less than a halfpenny. They re getting educated as to the amount of power that might be sted idly in a quick-return stroke, which became rather a formible amount. He had instanced only turbine cases, but engine bed ates and many kinds of planed work could be done advangeously by double cutting. The net outcome, in his mind, was at it was bad economy ever to use a quick return which put an erload upon the motor, or required to be provided with a larger tor than was required for the cutting power for that particular chine. In work, however, where the tools had to be frequently anged, not plain work where the only change was between the ghing and the scraping tool, but in work which had a great many gles and corners, and right and left-hand corner tools had to be d, and tools for rounding off the edges, especially if the work was rt, changing the tools in duplicate would take up the time that uld be otherwise saved by double cutting.

He thought the outcome of his remarks was that the two principles

of quick return and double cutting were meeting each other at a certain point. Tentatively, he would say that machines up to 4 or 5 ft. wide, and up to 10, 15, or 30 ft. long might, on the whole, be advantageously made with single cutting tools and quick return motion. With regard to machines from that size onward, namely, heavy machines 8 ft. to 10 ft. wide by 30 ft. to 40 ft. long, and so on, he thought that if the buyer did not yield himself entirely to the conservative advice of almost all workmen, and if he looked into the question for himself, and was not put off by trifling troubles of detail, he would find it advantageous to adopt the double cutting principle. Ineffectiveness of double cutting might be quoted to him by a workman or foreman simply because the box of which he individually had had experience had been made too light, or had a defective feed motion, but there was no reason why a double tool box should not be made just as strong as a single tool box. Exceptional cases might also be put forward where it was necessary to bolt a strong staff to the tool slide to reach down 3 or 4 ft. and take a decent cut with considerable overhang from the tool box. When that was the case, whether it was a double or single tool box, the whole tool box should be removed, and the staff should be bolted as close up to the cross-slide as possible.

He would not deal with the interesting and important details of drive for quick return machines on the present occasion. There was, however, a great deal to be said on that subject. Mr. Brackenbury alluded generally to the question, but he (Mr. Wicksteed) would not encroach upon the time of the meeting in that regard. He wished, however, to say, before sitting down, that he thought Mr. Brackenbury had performed a very useful service to the engineering profession in calling attention to the neglect with which the double cutting principle had hitherto been treated.

WILLIAM LODGE[1] said that in listening to the various papers which had been read, he could not help but think how rapidly engineers apparently were moving in the business under discussion, but he thought at the same time the papers were likely to be misleading to anyone who was an owner of a business and not practically engaged in the manipulation of the metals. For that reason he would call attention to the fact that the total time consumed in roughing operations in the building of almost any machine would not perhaps

[1] Mem.Am.Soc.M.E.

exceed one-quarter of the total hours involved in its manufacture, so that the saving effected was not likely to make engineers instantly rich if they bought high-speed steel or high-speed tools. He thought the taking care of some of the other features which tended to the practice of economy in the building of machinery was well worthy of attention. While he himself used high-speed steel, made machines purposely for its manipulation, and was an advocate of its use, in watching the progress made and the economies effected in the making of machinery he found there were a great many other things that could be practiced to advantage. In the endeavor to bring that about, the handling of making diameters and of making lengths which Mr. Calder illustrated in his remarks resulted in the saving of a great deal of time. He did not wish to call attention particularly to his own machines, but to the fact that if a sufficient amount of time could be saved in the various manipulations beyond the roughing, good would be done to the members of both Institutions.

The question of taking care of the time in which the work was done was also of great importance. The ordinary day-work method, allowing that all the men were honest, but were not thoroughly well looked after, was liable so to work out that, in the case of one man he would give one hour's work in ten hours; in the case of another man two hours' work in ten hours; and in the case of a third man, three hours' work in ten hours; and the question of finding how to handle the men and the work, and get the proper production, was just as important as the question of the high-speed steel.

The question had, no doubt, arisen in the minds of many of the members of how all the various pieces were to be sent through the works and delivered in the assembling room at the proper time. Many workshop engineers, or shop doctors as they were called, had gone into various establishments and said, "We can do wonders." The saving of the time that was formerly consumed in the mere roughing of a piece, to the extent of perhaps one-twentieth of the whole, was something, but it was a long way from taking care of the entire machine. He believed that if engineers were to give more attention to the work from the time it came into the shop until it arrived in the assembling room, it would be of more benefit to them than believing that they were getting rich because they were cutting metal very rapidly, a feature which consumed only a small part of the work of the machine.

He had had various systems under careful consideration with

regard to the question of beginning, and even some part of the best of them might be improved upon. For instance, in carrying the work through the shops a tag might be used, supplied with an ordinary office clamp and twelve coupons, in a case where twelve operations had to be performed upon one piece. The upper coupon described the first operation; it gave the time that the operation should be performed in, and such other information as was necessary. For instance, if it was done by piece work the time allowance would be given, and the same information was given if it was done under a premium system; but whatever way it was, it gave all the information necessary for the first operation. When the first operation was performed, the top coupon was taken off, and the next one showed that the piece must go to the roughing machine, and the time for the operation and any other information was given for that feature also. Then that coupon was also taken off and put into the finish box, and found its way to the cost room within an hour. The third coupon showed that the piece must next go to be turned ready for grinding, and the time for that operation and any other necessary information was given. The piece found its way automatically, from the time it left the cutting-off department to the time it arrived at the assembling room, merely because the man who did the trucking saw the next place to which it must go, carried out that operation himself, and did not require a foreman or a superintendent or anyone else to look after him. On the other hand, if there was an inspector in the department following the work he would inspect the work as it left the various departments, and forward the piece on for the next operation. He thought a little information on such matters would be, perhaps, of as much interest to the members of both Institutions as the question of high-speed steel.

DEMPSTER SMITH[1] said he wished to thank Mr. Brackenbury for his most interesting paper, in which he not only compared past practice with present, but gave them an idea of its trend and of some things yet to be accomplished in machine-tool design. He noticed with pleasure the recommendation that makers should be asked to guarantee the efficiency of their machines at various loads. That was a most important point, as the said measurements would reveal the principal capabilities of the machines. It went a step further than asking the makers to specify the cut the machine would take

[1] M.I.Mech.E., Municipal School of Technology, Manchester, Eng.

on a certain diameter at a given speed. At present the machine maker practically manufactured to his own specification, and, in the majority of cases, he did not know what cut his machine would take at the various speeds. The specification of a drilling machine, for example, usually stated that the machine would drill holes up to a certain diameter, but made no mention of the feed or speed while drilling the largest hole, and those were factors of equally great importance. The machine users were as much to blame for that state of affairs as the makers, since it was hardly to be expected that the latter would comply with conditions not stipulated. Should a certain efficiency or ratio of net work to belt work be insisted upon, it would cause many designs of all gear drives at present in use to be greatly modified or withdrawn altogether. Many of those had efficiencies less than 80 per cent. Very little was known about the durability of those gears at high speeds, or what proportions the wheels must be to secure the most satisfactory results. As a consequence the efficiency of some present designs, after a few years' running, might be quite different to that obtained when new.

It was difficult to understand what the author intended to convey in Par. 8, but it would appear that he had not a very high opinion of experimental research. He said: "Experiments made under ideal conditions are useful for some purposes, but useless as a guide to what is actually performed in the workshops." Experiments were made under such conditions in order to determine the ideal capabilities of tools or machines. What was actually performed in the workshop altogether depended upon the equipment and management. Further he said: "There are so many variations in the actual conditions that . . . it is difficult to say what is the best rate to cut at;" and, continuing, he supplemented F. W. Taylor's twelve variable elements[1]. It seemed that the subject was so involved as to be almost incapable of a solution. The twelve variables referred to were disputed by Dr. Nicolson and Mr. Adamson when Mr. Taylor presented his paper, and the conclusion from their remarks was that the cutting speed for roughing depended upon the quality of tool steel, cutting angle, shape of tool, the area of cut, quality of metal and was independent of the cross-section of the tool. Although Mr. Taylor, in The Art of Cutting Metals, adopted a very complicated expression for the cutting speed, it was capable of much simplification without introducing any error. Dr. Nicolson

[1] Trans. Am.Soc.M.E., vol. 28, p. 31.

had stated that the cutting speed depended upon the area of cut, that is, the depth of cut multiplied by traverse, as a single variable, whereas Mr. Taylor maintained that the cutting speed depended upon the depth of cut and traverse as independent variables. The reader of The Art of Cutting Metals would observe that all reference to the cutting speed varying with cut and traverse as independent factors was made in three sets of experiments carried out in 1884 with carbon steel tool. The variation in the cutting speed due to different depths of cuts was found by advancing the tool into the work in the ordinary way, the traverse being kept constant. To obtain the variation of speed with traverse, however, the traverse was kept constant, while the depth of cut and tool face were varied so that the shaving had a constant length but different thickness.

TABLE 11 COMPARISON BETWEEN RATIOS

	Depth of cut, in.	Cut Ratio	Cutting speed, ft. per min.	Speed ratio	Metal
1	0.125 0.375	1-3	15.5 12.25	1.27-1	Medium steel
	Thickness of shaving, in.	**Thickness ratio**	**Cutting speed, ft. per min.**	**Speed ratio**	**Metal**
2	0.01 0.03	1-3	33 16	2.06-1	Medium steel
3	0.005 0.015	1-3	15.1 8.8	1.72-1	Hard steel
					Mean 1.8-1

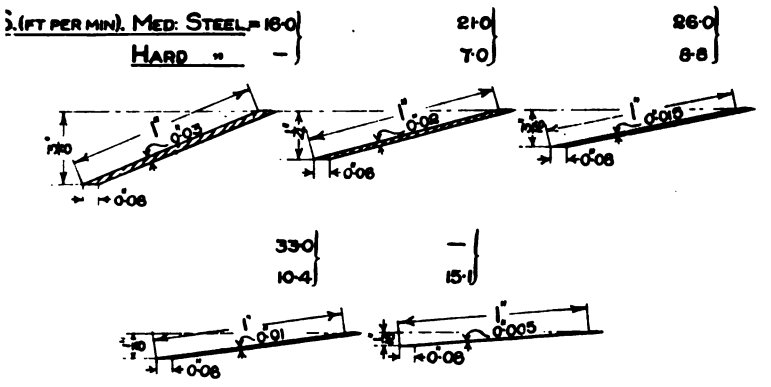
This would be understood from Fig. 22, which gave particulars of the tools and cuts taken in these experiments.

As different metal was used in these experiments, a comparison was made between the ratios, with the results shown in Table 11. Notwithstanding the difference of 20 per cent between 2 and 3 Mr. Taylor took the mean of those, 1.8, to compare with 1, and concluded by dividing the thickness of shaving by 3, increased the cutting speed 1.8 times, while dividing the depth by 3 increased the speed 1.27 times. That was equal to a difference of 40 per cent (See Pars. 292 and 299, also Folder 16). It was clear that by altering the angle at the tool nose, the path of the shaving had also been altered, and with it the true cutting angle. It had been shown by Dr. Nicolson in Experiments with a Lathe Tool Dynamometer,[1] read

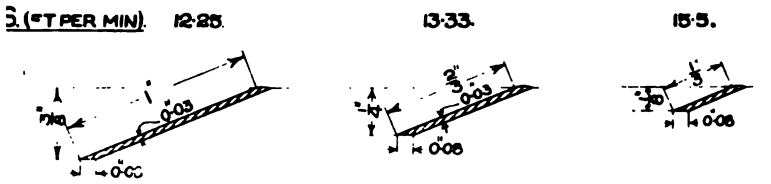
[1] Proc. I. Mech. E., 1904, Pt. 3, p. 883.

re the joint meeting at Chicago in 1904, that the cutting speed ed with the cutting angle. In the light of that evidence they d only conclude that the result obtained by Mr. Taylor for ation of speed with traverse, was actually due to a combined t of shaving thickness and cutting angle.

urther, it was shown by Dr. Nicolson that the character of failure high-speed steel tool was quite different to that of a carbon steel, iat even admitting that the above results obtained by Mr. Taylor



VARIATION OF CUTTING SPEED WITH DEPTH OF CUT.



. 22 MR. F. W. TAYLOR'S EXPERIMENTS. VARIATION OF CUTTING SPEED WITH THICKNESS OF SHAVING

right for carbon steel, they were clearly inapplicable to high- d steel, and that was supported by the fact that Mr. Taylor was ole to repeat the experiments with high-speed steel: "A similar s of experiments was planned by us with high-speed steel, but ig to lack of time have not been carried far enough to record paper." Nevertheless he (Mr. Taylor) advanced several sets of riments in support of his contention—that the cutting speed was pendently effected by the depth of cut and traverse. If the results n on Folders 8 and 11, and admitted by Mr. Taylor as the most

satisfactory series of trials on cast iron and steel were plotted on a base of area of cut and a contour line drawn through their mean, there would not be a difference of 5 per cent in the most extreme case. With the exception of one experiment the values given conformed to

$$V = \frac{6.5}{a^{\frac{1}{2}}} \text{ for steel}$$

$$V = \frac{11}{a^{\frac{1}{2}}} \text{ for cast iron}$$

within 5 per cent. There was no evidence of a 40 per cent difference there. If his final equation for steel be taken

$$V = \frac{\text{Constant}\left(1 - \frac{8}{7(32r)}\right)}{F^{\frac{2}{5}+\frac{2-12}{5+32r}}\left\{\frac{48}{32r}D\right\}^{\frac{2}{15}+0.06\sqrt{32r}+\frac{0.8\,(32r)}{6\,(32r)+48D}}}$$

where

V = cutting speed in ft. per min.
F = feed per revolution in in.
D = depth of cut in in.
r = radius of the tool nose

For durability it has long been the practice in this country when roughing to use a round-nose tool of $\frac{1}{2}$-in. radius or more. Substituting in the above equation $r = \frac{1}{2}$ in., the equation becomes

$$V = \frac{\text{Constant} \times 0.928}{F^{0.51}D^{0.504}} \text{ for } D = \tfrac{1}{32} \text{ in.}$$

$$V = \frac{\text{Constant} \times 0.928}{F^{0.51}D^{0.48}} \text{ for } D = \tfrac{1}{2} \text{ in.}$$

Taking the mean index of D and for all practical purposes, we have

$$V = \frac{\text{Constant}}{F^{0.5}D^{0.5}} = \frac{\text{Constant}}{a^{\frac{1}{2}}}$$

where a is the area of cut, that is $F \times D$. The differences in the above equations could not be determined experimentally. Similarly this equation for cast iron can be written

$$V = \frac{\text{Constant}}{a^{\frac{1}{2}}}$$

d this is exactly the expression given by Dr. Nicolson, namely

$$V = \frac{C}{a^n}$$

ıen allowance is made for the tool steel used

WALTER CARTER,[1] while agreeing with Mr. Brackenbury in much .at was given in the paper, differed from him in the manner of the vision of the high-speed steels. The divisions mentioned were, ı suggested, due to the difference of quality and cost. The steel assed as *C* would do anything that those steels of classes *A* and *B* ere capable of doing; in fact, would do considerably more, and could ı used further, and to advantage, if the user were prepared to pay higher price. He did not think it necessary for three classes of steels ı be used in a workshop in order to arrive at the best results.

Mr. Brackenbury had stated that less horsepower was required ı remove a pound of metal at high speeds than at low speeds, and ıdded that this was true only to a certain point. Would he kindly .ate at what point such economy ceased. From the speaker's per- ınal experience, he could confirm that considerable economy resulted om the use of high-speed steel, even when the speeds used were not igh, owing to the tools cutting for a much longer time without ıquiring grinding.

As regards the grinding of tools, he could not entirely support the uthor, as he thought it was not entirely advantageous to prohibit orkmen from occasionally grinding the tools they used. In many ases the tools required but touching up, and such could be done by the orkmen at less cost than by sending the tool to the grinding shop. he tools were, of course, always prepared by the grinding operators ı the first instance. He was in agreement with Mr. Brackenbury in ot becoming slaves to so-called standard angles and shapes. A little iscretion might reasonably be left to the foremen and workmen.

As regards the cutting angle of the tools used, he had found that tool having a cutting angle of 65 deg. with a 5-deg. clearance gave ery satisfactory results, for cutting either steel or cast iron. Refer- ing to the form of the tool, he suggested that the round-nose form as inefficient, and used only because of the ease of maintenance. here could be no doubt that a tool having a straight-line cutting dge was much more satisfactory. In the case of the round-nosed

[1] A.M.I.Mech.E., J. J. Saville & Co., Triumph Steel Works, Sheffield.

tool, a section taken through the tool in a vertical plane slightly behind the tip would show the top of the tool to approximate a straight line, whereas the tool actually cut a chip corresponding to the curved form of the cutting edge. This curved chip impinged on the somewhat straight top face of the tool, and a certain amount of pressure was naturally required to make this curved shape conform to the straight face on the top of the tool. In the case of a tool having a straight line for the cutting edge, the chip came off straight and without change of form, and therefore required less force than a chip made with a round-nosed tool. That, the speaker considered, was one

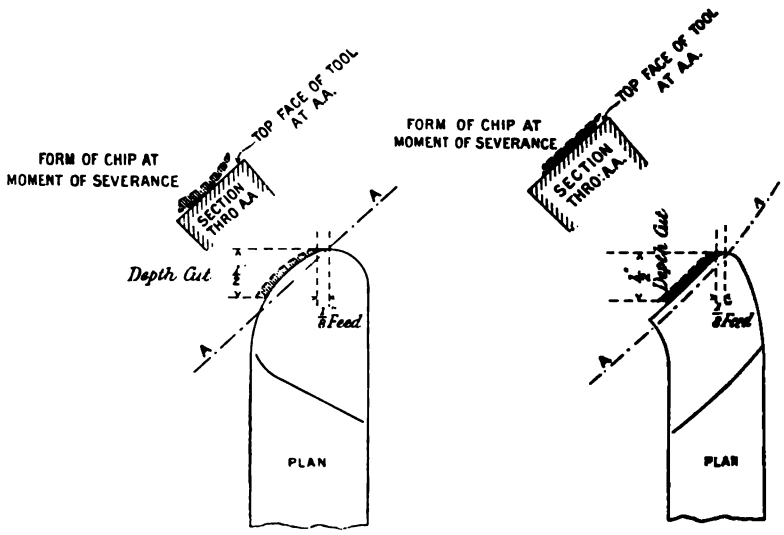


FIG. 23 ACTION OF CHIP WITH TOOLS HAVING CURVED AND STRAIGHT CUTTING EDGES

of the reasons for the improved results obtained with turning axles, mentioned by Mr. Brackenbury. Figs. 23 would illustrate this point.

He thought the comparison of tests under the heading of Economy in Power did not give sufficient detail, and therefore might become a little misleading. He assumed that the tests made at the works of Messrs. Alfred Herbert—certainly very fine tests—were made with the cutting tool lubricated, whereas the tests made at the Manchester School of Technology were made without lubrication, and the advantages of lubrication would be well understood.

References have been made to performances of twist drills and drilling machines. He therefore might be permitted to mention an in-

ance of a test made in a works at Birmingham in a machine which as possibly one of the most powerful yet constructed. The drill sed was 2⅝ in. in diameter, drilling a steel block 3½ in. deep. The lock was fairly hard, containing 0.35 per cent carbon and 0.65 per ent manganese. The drill was run at 127 r.p.m., feeding at the rate f 3 in. per min., and 6 holes were drilled without difficulty, the wist drill itself scarcely getting warm.

He was entirely with Mr. Brackenbury, that full advantage was ot even yet taken of high-speed steel, but at the same time he xpressed disappointment that practically no mention was made in he paper of the newer and improved high-speed steels, or of what could e done with machine tools when using them. As an instance of the reat superiority these steels possessed over the ordinary high-speed teels, he mentioned a test made between twist drills of the same naker, one being of ordinary high-speed steel and the other of the new high-speed steel. A test was made with $\frac{1}{8}$-in. diameter drills, drilling a hard cast iron block 3 in. deep at a feed of 5 in. per min., the drills making 333 r.p.m. The ordinary high-speed drills required grinding after drilling 4 holes, whereas the twist drills of the new high-speed steel drilled 23 holes before requiring grinding. It would seem, then, that much greater advantages were to be secured than were indicated in Mr. Brackenbury's paper.

As another instance of what could be effected by using really modern steel, a cast-iron face plate of 42-in. diameter, with the usual slots and holes in the face, was machined all over (taking the scale in 14 min.). The cutting speed was 100 ft. per min., the depth of cut $\frac{5}{16}$ in., and the feed $\frac{1}{8}$ in. per revolution, the lathe being fitted with driving apparatus designed to maintain a constant cutting speed. There was another case of a tool in which improvements had been made almost equal to the improvement in high-speed steel itself, and of which Mr. Brackenbury had made no mention. The particular tools the speaker had in mind were files. Usually very little attention was paid to the purchase and selection of files, which he (Mr. Carter) ventured to say was quite a mistake, as files were now obtainable which would cut twice as quickly as ordinary files, and at the same time would last from three to four times longer. No doubt Mr. Brackenbury had had experience of such files, and his remarks would be appreciated. To remove any misconceptions, he might say that he did not refer to what were known as milling files, but to files apparently cut in the usual Sheffield manner, but made of greatly improved and special steels.

In Table 5 the author had given some cutting speeds, it being stated that old hard railway tires were cut at 45 ft. per min. with $\frac{3}{8}$-in. depth of cut, and 6 cuts per in.; it was further stated that two tools finished 10 pairs of tires. Mr. Carter would have been glad to hear the views of the railway engineers in regard to this, as the results were certainly in excess of what was usually obtained. At the same time he might remark that steel capable of giving such results should show to greater advantage in cutting cast iron than 70 ft. per min., $\frac{1}{8}$-in. depth of cut, and 8 cuts per in. He ventured to state that these two results were scarcely consistent.

Mr. Lodge had remarked that the time which could be saved by roughing was limited, and in some cases not more than one-fourth, and indicated that economies could be effected by having machine tools so designed that changes could be effected with a minimum loss of time. He, the speaker, ventured to add that economies might also be achieved in another way, and that was in the grinding and preparation of the cutting tools. If there must be a correct cutting speed for the metals which were to be cut, there must also, he thought, be a correct cutting speed for the tools to be ground. If such were the case, efforts should be made towards running the grinding wheels and stones accordingly, whereas in many shops little or no attention seemed to be paid to this matter; stones were often run at the wrong speeds, sometimes too fast, sometimes too slow. They were not always true, while they were often of the wrong grit, and furnished only with a very defective water supply, consequently grinding the tools often took twice the length of time that would be consumed if proper appliances were installed, and those applicances maintained in an efficient condition.

In conclusion, the speaker would express his pleasure at the mention in the paper of the name of Mr. J. M. Gledhill, who had done so much to develop and extend the use of high-speed steel in this country.

FREDERICK W. TAYLOR[1] said the game of poker was played in America, and he was strongly reminded of poker playing in listening to some of the best American papers that had been presented to the meeting. He did not wish to detract in the slightest degree from the value of high-speed steel, but for the benefit of the younger men who were likely to read the American papers he suggested that in their practice they should discount the figures that had been given—cut them in two.

[1] Mem.Am.Soc.M.E.

r divide them by three, or something of that sort. What was said
ı these papers was strictly true. It was natural, however, to wish
› put one's best foot foremost, and it was best in practice not to
ttempt to do the very maximum. The proceedings of the American
ociety had been burdened to such an extent with what he had said
n the subject of high-speed steel and similar topics, that he felt it
'ould be improper for him to make any further remarks on that point.
[e welcomed the opportunity, however, of speaking upon the far
roader subject of which the art of cutting metals and the proper
se of machine tools was but one of the small elements, namely, the
reat opportunity, as well as the duty, which lay before them as engi-
ıeers of taking such steps as would, during the next few years, result
n a very material increase in the output of every man and every
nachine in their manufacturing establishments. The importance of
›btaining that increase of output was that, in his mind, it presented
:he only opportunity open to them, measurably speaking, of settling
the great labor problem which faced both of their countries. He said
without hesitation that in the average establishments in America,
not in all the establishments, it was possible to double the output of
the men and the machines just as they stood now, and he believed the
same was true throughout this country. It gave them the oppor-
tunity at the same time to give the men what they most wanted,
higher wages, shorter hours, better working conditions; and, on the
other hand, to give the companies what they most needed, a lower
labor cost, so that they might be able more successfully to compete at
home and abroad.

The problem of increasing the productive capacity of their men
divided itself naturally and readily into two sections, on the first of
which he wished to say a few words, and on the second of which he
would like to speak at rather greater length. The first duty which
lay before them as engineers was that of counteracting and overcom-
ing the blighting fallacy which rested upon every one of their workmen,
and which was paralyzing their energies, that it was to the best inter-
ests of the workmen to go slow instead of going fast, to do as little as
possible for the money they were getting instead of as much as possi-
ble. There was hardly a labor union in either of the countries which
had not already enacted restrictive legislation upon these principles.
And every workman, from the time that he started to serve his appren-
ticeship, was deliberately taught by the men who were older than him-
self that it was to his best interests to soldier, as Americans call it, or
to hang it out, as Englishmen called it, instead of going fast. He did

not propose to say anything more on that subject except to ask the following question: What were they, as engineers, who understood the evils of soldiering, who understood the extent to which their men were underworking, and who understood that that must inevitably mean low wages in the long run for their men, a higher cost of living for the men, and diminished prosperity for the whole community—what were they, as engineers, doing to counteract that fallacy?

It was on the second element that he wished to speak more particularly, namely, the possibility which existed, which Mr. Lodge and one or two other speakers had referred to, of increasing the output of their working men through deliberate scientific study of the motions of men, followed by a time study of their motions. The extent to which this output might be increased could be appreciated only by those who had made such a study, or who had seen it made, and he did not expect anyone to rest satisfied on that point by a mere assertion made by a speaker. With the permission of the meeting, he would like to give one simple illustration of the possibility of increasing the productivity of men by this scientific motion study; and he predicted that during the next fifty years a very considerable part of the time of engineers would be spent in the minute motion study of every man in every trade. The effect of it was enormous. The illustration he wished to give was purposely taken from another field than that of machine tool practice, for the reason that he wished to give an exceedingly elementary illustration, and it was only one of thousands of similar illustrations which might be given. Motion study had been going on in the United States for more than thirty years in increasing volume, and invariably with the same result, namely, an enormous increase in the productivity of man if it was properly carried out.

Bricklaying was, perhaps, the oldest of the mechanic arts that were now practiced. Two thousand years before Christ bricks were laid as they were now laid. The same kind of brick, the same kind of mortar, the same kind of trowel, and the same kind of scaffold were now used as at that period. If any trade had reached a point at which motion study would be non-productive, one would therefore expect to find the bricklaying trade in that condition, because 4000 years of work, with thousands of men working throughout the world at the trade, should certainly have evolved a good system of bricklaying. Some four years ago Frank B. Gilbreth, who was present at the meeting, became interested in motion study. During his youth, Mr. Gilbreth made a very close and accurate study of bricklaying, and he

ore said to himself that if there was anything in the new idea tion study it ought to be as useful in bricklaying as in any- else.

(Mr. Taylor) would briefly go through the study which Mr. ɜth made. He found himself standing on a scaffold with a pile cks on the floor and the mortar board alongside him, a brick ɔeing built on the left. The first motion made by a bricklayer ɔ take a step to the right. Was that step necessary? He would later on that the step was not necessary. Next, after taking ep to the right, the bricklayer stooped down to the floor, dis- ed a brick from the pile of bricks, and raised his body up again, to full height or to partial height. Was it necessary for the ayer to lower a 240-lb. weight to the floor in order to raise lb. brick 2½ ft.? Mr. Gilbreth, after a great deal of work, ɔd a scaffold on which the bricks were placed at the same level the wall, and kept at the same level at all times with the wall. s a scaffold on which the man stood in one place, while a little was placed alongside him on which the bricks and mortar rested. was a very simple invention, but why was it not done 4000 years ɪr why had it not been done in the meantime? Because no one ıade a scientific motion study of the bricklayer. The bricks were l on this supplementary platform at just the right height, so the bricklayer merely turned round, picked up a brick with a / motion of the body and put it on the wall. Mr. Gilbreth then . that every bricklayer, as he raised the brick, threw it over hand at least once, sometimes twice, sometimes three times. was done for the purpose of examining whether the brick was l and not chipped; he would not put a brick with a chip out of it e outside of the wall where it showed. He therefore threw up rick from habit, apparently just for the fun of it; he threw a second time to look at the edges, and sometimes a third time ɜ he laid it on the wall. Mr. Gilbreth said, Was that necessary? ıfter a great deal of thought he devised the following plan for away with all of these motions. As the bricks were unloaded the car or from the team, a laborer was stationed at a suitable ı, where the bricks were examined by him, and placed right side ith the proper edge and the proper end on a wooden frame about feet long; this frame held about ninety pounds of bricks, and was ıstructed that the bricklayer's hand went right into it and seized rick without having to disengage it from the tangle on the floor. ok the brick out in the exact position in which it was to be laid wall, without any throwing and without any change of position.

Mr. Gilbreth next found that the bricklayer worked with one hand only at a time. Why? Because the brick pile being on the floor and the mortar board some distance from it, they were too far apart for the man to take a dip of the mortar and pick up a brick at the same time; it took two motions. By building the scaffold in the way he had described, and by placing the bricks and the mortar close together, using a deep mortar box instead of a mortar board, brick pile and mortar box were brought within the range of the bricklayer's two eyes at the same time, so that he picked up a brick with the left hand, took a dip of mortar with the right hand with a single movement as far as time was concerned, then turned around, spread the mortar, and laid the brick in the wall. The step which was first taken by the bricklayer had been abolished, by reason of the fact that Mr. Gilbreth had studied in great detail the exact position which the feet of the workman should occupy with relation to the wall on the left and the brick and mortar on the right, in order to reach his brick pile and mortar with the greatest ease in the several different kinds of bricklaying. The workman, if he had his feet in the proper position, could move from one to the other without a step. The scaffold had been made adjustable, so that a cheap workman was able to walk all day long round the building and adjust the scaffold with the workmen on it to its new height, keeping the wall and the bricks and the workman at all times at the proper height as they went along. The workman did not have to stop while the scaffold was adjusted. Mr. Gilbreth also found that all bricklayers, after they set the brick, tapped it down in order to get the joint the right thickness. From his experience in his youth Mr. Gilbreth knew that if the mortar was properly tempered it was possible to take the brick and press it with the hand to the right height. The mortar was therefore carefully tempered, so that the bricklayer could readily press the brick to the right height and thus save the time taken in tapping.

He desired to summarize what had been done, because it was typical of what could be accomplished in every trade, without exception. He did not say that as much as this could be accomplished in all cases, and yet it was typical of what could be done through motion and time study in every trade, provided sufficient attention was given to the subject. He believed it was three years before Mr. Gilbreth finally completed his motion study, and obtained the full benefit from it, so that the motions of the bricklayer were reduced from eighteen to five, and in one case from eighteen to two. The reduction

of the motions from eighteen to five or two would practically amount, as the members would easily realize, to nothing, provided the men's unions said nay, and the unions always did say nay. But Mr. Gilbreth, who happened to be an optimist as well as a man of great pertinacity, bided his time, and finally he had his opportunity with the Bricklayers' Union of Boston. He showed the leaders of the union that bricklaying in America was likely to become a lost art, because reinforced concrete construction was growing at such a pace, and he persuaded the leaders of the union to give him a chance to show what he could do, if he was not thwarted. Mr. Gilbreth was erecting a large building in the neighborhood of Boston, and he told the bricklayers, in the first place, that he would not employ any of them at less than $6.50 a day, the ruling price in Boston being then $4.50 a day. That was a very satisfactory proposition to the workmen; but he also stipulated that any bricklayer who did not do exactly what he was told would be promptly discharged. By the time the building was from a quarter to half-way up he had a full complement of bricklayers laying bricks according to the new method, and each of them getting $6.50 a day. On a 12-in. wall, with drawn joints on both sides, using two kinds of bricks, which all practical men would know was not an easy wall to lay, the average was 350 bricks per man per hour, the record number of bricks which had been laid per man per hour in this type of work previous to the adoption of the new system being 120 bricks.

He desired to call attention to one other element, which was really the vital element involved in the new system. The bricklayers who were employed were not left to their own devices; they were not told, We will give you big wages; you go and lay the bricks fast; you know how the work should be done. They were told, We will pay you big wages if you will do exactly what we tell you to do, and if you do it fast. Mr. Gilbreth further did the only thing which was capable of bringing success in bricklaying. He had no doubt that, in the last 4 000 years, many bricklayers had thought of practically everything that Mr. Gilbreth thought of, but not one of them was capable of practicing it without the coöperation of the master bricklayer or of the contractor who employed them. No group of bricklayers even could practice the new method without the aid of the man who was over them. It required coöperation between the management and the men to accomplish the new results, because, in the first place, the workmen unaided were incapable of eliminating those bricklayers who would not conform to the new rules; and since in bricklaying two or three

incompetent or slow men could hold back and limit the quantity of work done by, say, twenty or thirty others, it was absolutely necessary that these incompetents should be discharged. The only person who could eliminate them was the owner or the person in charge of the work. In the second place, the practice of Mr. Gilbreth's new method called for a new type of scaffold and mortar-box and other simple apparatus, such as the wooden frames upon which the bricks were systematically piled; and, simple as this apparatus was, it could only be supplied by the master, not by the workmen. Thus it became clear that the new or scientific method called for deliberate coöperation between the workmen and those over them, as well as for painstaking, thoughtful motion and time study, which should be made by those in the management, and which, in fact, was, in most cases, entirely beyond the ability and training of the workman.

FRANK B. GILBRETH,[1] who was called upon by the president, said that he had nothing to add to the remarks of Mr. Taylor.

JOHN A. F. ASPINALL,[2] before calling upon Mr. Brackenbury to reply, said he would have liked to ask more speakers to make remarks upon the paper, as he knew there were a number who desired to do so, but as they had been good enough to prepare their notes he asked them to send them in to the secretary, in order that they might be published in the Proceedings.

DANIEL ADAMSON[3] wrote that Mr. Brackenbury referred to the advantage that would accrue to purchasers if machine-tool builders would give the total efficiency of the lathe and motor at various speeds and loads; and there was no doubt that this most important feature was practically ignored. A reference to Figs. 5 and 6 seemed to prove the necessity for some such stipulation, when purchasing new machines, assuming the pressure of the chip on the tool as 100 tons per sq. in., the net output at the cutting speed of 18 ft. per min. referred to by the author was only about 33 per cent of the electrical horsepower and even at 33 ft. per min. under 60 per cent. Consideration of this feature seemed to throw some doubt upon the suitability of the method adopted in Table 7 of stat-

[1] Mem.Am.Soc.M.E.

[2] President I. Mech. E., Gen. Mgr. L. & Y. Ry., Hunts' Bank, Manchester, Eng.

[3] M.I.Mech.E., Messrs. Joseph Adamson and Co., Hyde, Eng.

ng the power delivered by the belt to the machine, because while it was evident that more power could be transmitted by the belt at the highest speeds than at the lowest, the loss in the gearing would be a variable quantity, and consequently Table 7 gave no indication of the pressure to be expected at the tool.

It would considerably enhance the value of Table 7 if the author would give the ratio of back gear on these lathes and the range of spindle speeds for each, and also the number of intermediate steps on the cones, so that some estimates could be made of the torque available at the spindle at different speeds of revolution, as suggested by Dr. Nicolson in his book on Lathe Design; also referred to in Professor Rautenstrauch's recent paper before The American Society of Mechanical Engineers.[1]

While discussing this matter of efficiency of machine tools (considered as mechanism for transmission of power), he would like to refer to Mr. Brackenbury's paper where a certain lathe was said to have consumed upwards of 80 h.p. There was no information about the quality of the steel being cut, but a reasonable assumption would give a net output of work at the tool point of about 70 h.p., thus indicating a very high efficiency of transmission, so high in fact as to throw doubt upon the figures given. Perhaps the author would clear up this in his reply.

Referring now to the more commercial side of the question, as outlined by the author he (Mr. Adamson) must frankly confess that he did not understand Fig. 4 or the explanation(Table 2), or even the line of thought upon which the author had based his illustration. It was very evident that for a machine which cost £1000, the charge of 1*s.* per hr. suggested by the author did not include many items of expense which must be taken into consideration, when making a comparison between different machines.

To refer to more detailed matters, he thought that the author ought to furnish further information regarding the cast-iron wormwheel which he mentioned as having been almost entirely worn away in a few days. If the author would mention the power transmitted or the load on the teeth and the speed of rubbing, also the pitch and other usual details, the information would be most useful to designers of machinery. A similar question might be asked regarding the pitch of the screw in the back center of the lathe referred to in Fig. 10. Without this information the length of the lever or the pull at the end was useless.

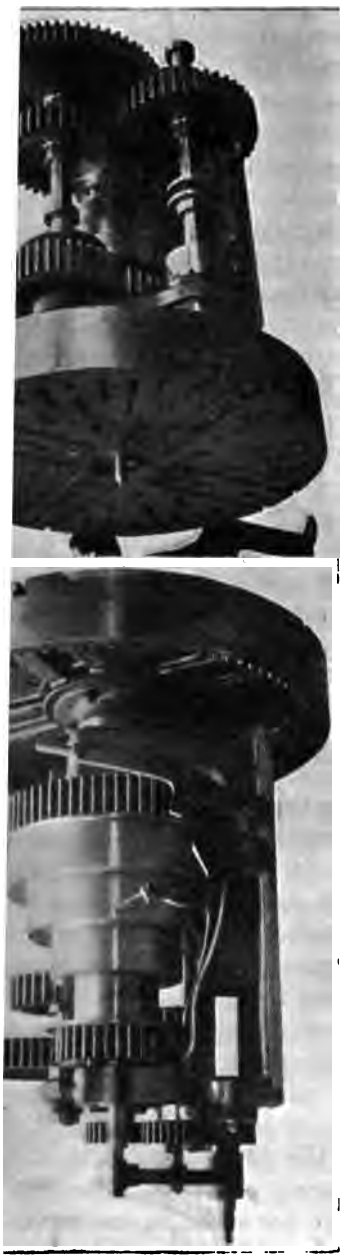
[1] The Journal Am.Soc.M.E., June 1910, p. 1011.

Table 4 seemed to the writer to be incomplete without some information as to the life of the drills made from *Class A* steels under the conditions named, while Table 5 would be very much improved if a statement of the power required in each of the tests were added. The author referred (Par. 46) to the weakness of old jib-drilling machines, and it might be of interest to the members if he mentioned that his firm had been very successful in their own works in improving old jib-drilling machines by putting on entirely new saddles, because, as the author stated, the arrangement for feeding and withdrawing the spindle was generally the most unsatisfactory feature of such old machines. He hoped that the author would see his way to furnish the additional information asked for, and thus make his paper more valuable as a work of reference for purchasers and designers of machines for the use of high-speed steel tools.

GEORGE ADDY[1] wrote that on reading Mr. Brackenbury's paper, he had been greatly struck by the amount of valuable data given to all those who were interested in machine tools. One admirable feature to be commended was that the author had avoided the temptation to exaggerate where he remarked that he had known a case where a high-speed steel tool had run for a day without requiring to be ground. In the writer's own experience he had met with high-speed steel which would run seven or eight days without grinding. The author seemed disposed to recommend high-speed steel for all purposes; with this he (Mr. Addy) could not agree, for admitting the utility of this steel for many operations, he contended that it was by no means the most economical way of working a machine shop to use nothing else but high-speed steel. In the average engineer's workshop, there were many operations, which, owing to the shape of the article to be turned, did not admit of being shaped at high speeds, as for instance, when there were many necks and collars on forgings. His own impression was, that it was the best plan to have certainly not more than 50 per cent of the total steel tool used made of high-speed steel, the other 50 per cent being ordinary carbon steel of a price not exceeding 6*d*. per lb. as compared with the latest high-speed steel costing approximately 3*s*. per lb.

He was glad to see that Mr. Brackenbury had drawn attention to the mistake which was sometimes made of scrapping heavy substantial lathes because the driving power was insufficient, when by sub-

[1] M.I.Mech.E., Wavcrley Works, Sheffield, Eng.



24-IN. CENTERS, FRONT AND BACK

10-IN. CENTERS, GEAR WHEELS GUARDED

14-IN. CENTERS, GEAR WHEELS GUARDED

FIG. 24 HIGH-SPEED FAST HEADSTOCKS

stituting new high-speed fast headstocks, these old lathes could be easily turned into most valuable high-speed lathes. The writer did not think this aspect of the case had had the consideration paid to it which it deserved, for soon after the introduction of high-speed steel he was strongly impressed with the necessity of bringing old lathes up to date by substituting a new high-speed fast headstock for the old fast headstock which was deficient in driving power, and the results had been eminently satisfactory. The principal thing to be aimed at in a new high-speed fast headstock was to have plenty of belt power, and so to arrange the gearing that with a countershaft running at the normal speed one obtained a very high spindle speed. He quite agreed with Mr. Brackenbury about the importance of having a very strong steel spindle with a very large front bearing, and the dimensions which the writer had adopted were approximately those given in Par. 34. He found it better in all cases when running on the slowest speed to have a pinion running into a face-plate wheel; by this means torsion of the spindle was avoided.

It was in 1905 that the writer began to produce these improved high-speed fast headstocks, and it was in 1905 that he converted three lathes by the substitution of high-speed fast headstocks, for a firm in the Midlands (Fig 24). The difference made by these three headstocks in that particular machine shop was startling, for the manager stated that before the conversion of these lathes, the crane had comfortably served all the lathes in that machine shop, but after these conversions had been effected it was found that it was necessary to get another crane to avoid the lathes being kept standing for want of work, as it had been found possible to exactly double the output; two of the headstocks had 16-in. centers, and the third one was of somewhat massive construction, being of 24-in. center and weighing 6½ tons.

As it might be of interest to have particulars of the method adopted and the dimensions of the various parts, the writer furnished them herewith. With high-speed improved fast headstocks, it was usual to supply a countershaft with two sets of pulleys of different diameters, so that with a 4-speed cone and the changes of gearing effected by the handles shown in front of fast headstock, 24 spindle speeds could be obtained, namely, revolutions per minute, 3¼, 5, 5½, 7½, 8¼, 9½, 11, 11½, 14½, 17, 18¼, 25⅜, 27½, 32¾, 38, 45⅜, 48½, 68, 73⅜, 101⅜, 110, 120, 152, and 194, the object being to supply a headstock, on which the minimum cutting speed was over 40 ft. per min. In this way the tendency on the part of some workmen to run at low speed was successfully combated, as it was well known that many powerful machines

were provided with slow gears were on that account never
d up to their full capacity.

IXANDER TAYLOR.[1] *Roughing and Finishing Motor Shafts.*
can railway shafts, after being cut off and centered, are handled
ɜe machines, namely, a roughing lathe, a spotting lathe, and a
ɪr. As the rough turning is worked under the bonus system,
erable trouble is experienced in keeping the stock allowance
inding down to a minimum. As the operation of turning is
ɪ roughing, the operator, knowing that a finishing operation
ɔllow, plays safe and at the same time works for speed by leav-
ɔnsiderably more stock for grinding than is necessary. By
ring various shafts in the factory, say from 1 in. to 4 in. in
ter, it was found that the stock left to be ground was from 0.1
0.042 in. As the shafts are turned with a very coarse feed, one
ɜnerally being taken, it is evident that more stock is required
if a fine feed were used. His firm has made several vigorous
pts to hold the stock allowance to a minimum, but always to
regret, because when the shafts reached the grinder quite a
er were found where tool marks could not be ground out and
ıafts had to be discarded.

ɜ grinding of shafts is also worked under the bonus system, and
again trouble has been experienced in setting limits because
ɔck allowance varies so much. In trying to eliminate this
ɜe his company has lately installed lathes for roughing and spot-
hafts in the same machine, thus saving the operation of taking
to another machine for spotting. These lathes are provided
wo tool posts, one in front for roughing, and one in back for spot-
and the carriage is provided with diameter and length stops.
wheels are not pinned or keyed, but are set so that the friction
ısure uniform contact with stops, thus eliminating variations in
ɪter, which are caused by errors in calipering. This takes the
of calipering and measuring out of the operator's hands alto-
r. When the machine is once set, it will turn out duplicate
thus requiring a less experienced man. The machine is run at
ting speed of about 100 ft. per min. on axle steel with a $\frac{1}{16}$-in.
By use of this fine feed, less stock can be allowed for grinding.
ɜe shafts are smoother and more uniform and have less stock
removed, the saving on grinding will average 25 per cent.

ɜm.Am.Soc.M.E.

The saving on abrasive wheels is also considerable. On smaller shafts a large saving can be shown on the rough turning as shown by Table 12.

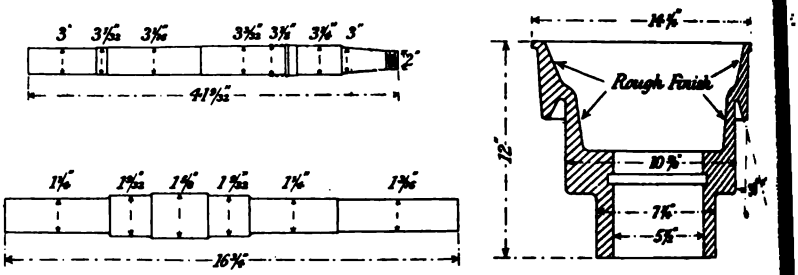


FIG. 25, 26, 27 RAILWAY MOTOR SHAFTS AND COMMUTATOR SPIDER

Table 12 shows the actual time required for finishing one of his company's railway motor-shafts (Fig. 25) by the new method, as compared with the old method, where they used a cutting speed of about 35 ft. and $\frac{1}{10}$-in. feed. The roughing and spotting time is very nearly the same in either case, the saving being in the grinding.

TABLE 12 TIME FINISHING RAILWAY MOTOR SHAFT

NEW METHOD

Operation	Average Time Each	
	hr.	min.
Rough, turn, spot and thread	0	30
Grind body	0	30
Total	1	30

OLD METHOD

Rough and turn	0	25
Spot and thread	0	25
Grind body	0	45
Total	1	35

Table 13 shows the result of a test made on ten shafts (Fig. 26) in a special engine lathe, as compared with the time required on a turret lathe. The engine lathe was equipped with diameter and length

stops, shafts were cut off and run between centers and turning was done at a speed of 330 r.p.m., with a feed of $\frac{1}{80}$ in. When the shafts are turned in a turret lathe, they are cut from bar stock, and as the bar projects over the end of the machine, the speed used on the engine lathe is not permissible.

TABLE 13 TIME TEST ON SPECIAL ENGINE LATHE AND TURRET LATHE

SPECIAL ENGINE LATHE

Operation	Average Time Each	
	min.	sec.
Cut-off (cutting-off machine)	3	0
Center, rough turn and spot short end	3	18
Center, rough turn and spot long end	5	6
Total	11	24

TURRET LATHE

Operation	Average Time Each	
	min.	sec.
Center, rough turn, long end and cut-off	12	0
Center, rough turn, short end and cut-off	4	30
Spot for grinder (engine-lathe with special fixture)	3	0
Total	19	30

Multi-cutting on Small Boring Mills. The use of two or more tools working in different places on the same piece of work at the same time has been universally demonstrated on turret lathes, screw machines, large boring mills, etc., but not to such a great extent on small boring mills, say, under 40 in. By adopting small boring mills or vertical turret lathes with side heads. considerable reductions in cost have been made on such parts as spiders, commutator bushings, etc. The latest example is on a cast-steel commutator spider as shown in Fig. 27. This job is machined on a 36-in. vertical turret lathe having turret tool holders on both main and side heads, and a taper attachment on side head for turning a taper on the largest diameter.

Both heads are used continuously throughout the entire machining operation, the 30-deg. dovetail is roughed and finished with formed tools, the angles on the parts marked rough finish are turned by shifting the main head to the proper stops. In order to obtain a high cut-

ting speed, a steady flow of soda water is played on the tools when cutting, the table being arranged to drain water without splashing.

Two settings are required to complete this spider. On the first setting the spider is gripped by the flange on the largest diameter, and the inside bore and the outside are finished accurately to gage. For the second operation, the spider is turned round, clamped in a pot chuck, and finished complete.

	hr.	min.
Time of first operation	1	25
Time of second operation	1	0
Total	2	25

This work was formerly done on a 42-in. mill, with a single head.

	hr.	min.
Time first operation	6	0
Time second operation	2	0
Total	8	0

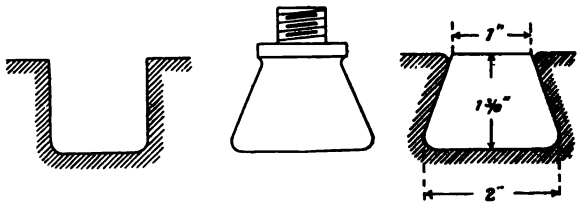


FIG. 28 MILLING DOVETAIL SLOTS

Milling with Formed Cutters. In general, the progress made on speeding up formed milling cutters, especially T-slot and dovetail cutters, has been somewhat slow, probably due to the high cost of cutters. The Westinghouse Company's large cast-iron spiders are slotted on a portable drilling and milling machine. A straight slot is first milled in the casting as shown in Fig. 28. A dovetail cutter is then run through. This cutter is made from high-speed steel and run at 76 r.p.m. with a feed of 3⅛ in. per min. and a cutting speed of 40 ft. per min. This feed and speed was maintained in cutting forty-eight slots 34 in. long, and the cutter was still in good condition.

inding versus Milling. They have found that a consider-
ıg can be effected by the use of disc grinders on surfaces
formerly milled, but this method is limited to flat surfaces,
ıving depends largely on the size and shape of the work.
forgings or steel castings which have flat surfaces to be
they have often found the metal chilled and almost impos-
ıill. Work of this kind is being ground by disc grinders
t economy, thus eliminating the trouble experienced in
Grinding also avoids the spring in castings caused by chuck-
ıping for milling.

4 shows the actual time required to mill, as compared
required on disc grinders. The saving would appear
figures were given in dollars and cents, as operators
ınders are paid 16 cents to 18 cents per hr., compared with
ıchine hands at 20 cents to 24 cents.

COMPARATIVE TIME REQUIRED FOR MILLING AND GRINDING

Part	Operation	Milling	Grinding
		min.	min.
cks	Machine top and bottom	3	1¼
ıd	Machine base	6	2
	Machine base	10	2
	Machine sides	3	1
	Machine partings	6	1
	Machine sides	3	1¼
	Machine sides	6	1¾
guide block brass	Machine top and bottom	2¼	1¼
	Machine partings	3¼	2

ı *Dies and Punches on Vertical Surface Grinders.* Con-
ıving has been effected by grinding small dies and punches
surface grinders with cup-shaped wheels. This work was
one on grinders with horizontal spindles. On small dies
ces up to about 3 in. by 6 in., the saving in time is about
t, and on large dies up to the capacity of the machine, the
bout 50 per cent. The cost of wheels per month for the
inder is about five times that of the horizontal grinder,
he vertical grinder turns out from 50 to 75 per cent more
wheel cost per die is very little more.

ıus Milling. In milling operations considerable time is
cking or clamping work, especially on small work where
kes as long as the milling operation. As the machine is

idle when the operator is chucking work, and vice versa, the efficiency of both operator and machine is reduced. To overcome this difficulty one man used to run two machines, increasing the efficiency of the workman; but this cut down the output per machine, as jobs very seldom allowed the operator to set up work in one machine while the other was in operation, and not have either of the machines entirely idle.

It is possible to obtain the highest efficiency from both operator and machine only while the workman is chucking another piece in in the case where the work or the castings are of such size and shape that a circular milling attachment can be used, or where a machine with a reciprocating fixture is employed. When used effectively, this comes very near to a continuous milling operation.

The Westinghouse Company is using a vertical machine with a circular attachment for milling sad-iron bases. This circular attachment is provided with ten independent chucks for clamping the castings, allowing the operator to take out the completed casting and replace it without interfering with the operation of the cutter. The cutter is 8 in. in diameter, with high-speed inserted blades running at a cutting speed of 42 ft. per min., and the work revolves so as to give a feed of 12½ in. per min. This work was formerly done on two vertical milling machines with transverse feed, magnetic chuck, and high-speed cutters, one operator running both machines. With the new machine the output has been doubled, and at the same time 50 per cent in floor space has been saved.

CLOSURES

H. I. BRACKENBURY wrote in further reply that his paper would not have been written in vain had it obtained no other results than to draw from Mr. Wicksteed his masterly comparison of the principles of single or double-cutting boxes on planing machines which was worthy of the most careful consideration of all users and builders of planing machines.

Mr. Dempster Smith had previously disputed the need for the twelve variable elements given by F. W. Taylor, and naturally resented the introduction of another and the most difficult of all these elements, namely, that of human endurance and energy, a matter which must be left to the tact of the shop manager or foreman. The author did not wish to intervene in a discussion raised so long ago between such eminent masters of experimental research as Mr.

Smith and Mr. Taylor; but he would like to state one difficulty which he felt against accepting the theory of equal endurance for equal areas of cut of any form.

In Fig. 29 the work is reduced 1 in. on the diameter. Then, according to Mr. Smith, the cutting speed was the same for equal endurance whether the shape of the cutting area was as A or A^1 if $A = A^1$. If the depth of cut were reduced to $\frac{1}{4}$ in., the area became $\frac{A}{2}$ and the cutting speed could be increased by 40 per cent by the formula $V = \frac{C}{A^{\frac{1}{4}}}$. This cut was taken by tool T^1. Place a similar tool T^2 behind T^1 to take the remaining $\frac{1}{4}$ in. depth of cut, the area of the cut taken by the tools T^1 and T^2 was now equal to A, but the speed might still be kept up to 40 per cent above the original method. At what point of juxtaposition would the tools T^1

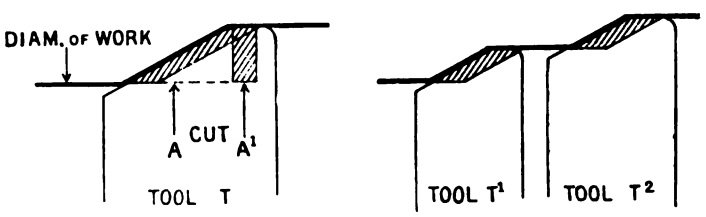


FIG. 29 WORK REDUCED TO 1 IN. ON THE DIAMETER

and T^2 count as one tool and lose the important property of 40 per cent extra speed for equal endurance? If tool T were replaced by four tools, the cutting speed according to the above formula might be doubled to give the same period of endurance.

The accuracy of the statement that to remove a thin wide chip required more power than to remove a thick narrow chip of the same area, had also been called in question; if the reverse were the case, it was difficult to understand why so much more power was required to remove the thin chips of the milling cutter than the thicker chips from the lathe. It would therefore appear that Dr. Nicolson's figures could only be an approximation of the truth within the scope of usual lathe practice.

One example occurred to the author which would appeal to the ordinary shop engineer. A surface 4 in. wide had to be milled by an end mill, the depth of cut being about $\frac{5}{8}$ in. The machine could not be persuaded to drive this cut at a travel of 2 in. per min.;

the milling cutter was replaced by a block carrying five round-nose tools, each tool taking a cut $\frac{1}{8}$-in. deep, and there was never any further difficulty in driving the cut.

Mr. Carter had asked at what point the economy of removing material at high speeds ceased (p. 781); this point was reached when the machine was pressed beyond the amount the design and construction permitted without undue friction. Mr. Carter had forwarded a design of two tools with round noses, one with a straight side and the other with a curved side, Fig. 23. There was little doubt that everyone would agree that the straight-sided tool would absorb a little less power for the same area of cut.

Mr. Carter raised the question of the effect of the lubrication of the cutting tool as regards the power absorbed. No doubt the tool would stand a higher cutting speed if a flow of lubricant were used, but it did not seem at all certain that at high speeds the use of lubricant would reduce the power absorbed. A considerable amount of power was required to bend the cutting on the face of the tool, and this bending power would be less for a very hot cutting than a cold cutting. Most engineers had noticed how the cuttings formed into small curls at a slow speed and how the diameter of these curls increased as the speed and temperature of the cutting increased, until the cutting seemed to be drawn off in almost straight pieces when it assumed a black color, and the face of the tool where the cutting impinged was a dull red. The author would be glad to have his attention drawn to any really conclusive experiments on the above question.

Mr. Carter had stated that practically no mention was made of modern high-speed steel, and further that greater advantages should be claimed for this steel than those indicated in the paper. The author would reply that he had dealt with this steel under *Class C* (Par. 5), and that although individual cases might be given showing greater advantages than those indicated, he thought the figures given were correct for general purposes. Regarding Mr. Carter's remarks on the importance of testing files, the author thoroughly agreed. He had constructed a very simple machine for testing files which practically imitated the action of hand-filing and gave very uniform results; the latest files of the Sheffield type had given results both in rapidity of cutting and length of life greatly in advance of those tested a year or two ago. In several instances the results bore out Mr. Carter's figures. Mr. Carter had drawn attention to economies which might be achieved in the grinding and preparation of cutting tools; the author of the paper thought

his was an important point, and one which should be carefully ratched by shop managers.

Mr. Adamson had asked for further particulars regarding Table 7. The information was as given in Table 15. The author regretted ıe could not supply the information regarding the loss of power n the gearing at various speeds.

TABLE 15 SIZE OF LATHE

	42-in.	36-in.	21-in.	14-in.	8-in.	6-in.
)iameter of cone	20 25	16 21	12½ 15½	9 12	4½ 6½	4 5½
teps in inches.....	30 35 41	26 31 36	18½ 21½	15 18	9 11½	6½ 8½
	1.56 to 1	1.58 to 1	5.46 to 1	12.7 to 1	10.5 to 1	6.25 to 1
earratio....	5.9 to 1	5.84 to 1	18.2 to 1	.....	.....	.....
	35 to 1	31.8 to 1	43.9 to 1	.....	.....	.....
	136 to 1	117.6 to 1	.....	.....	.....	.....

With regard to the consumption of power for the 18-in. lathe, ıe material cut was medium forged steel; the machine was specially esigned for running at a high duty, and was shown to be very effi- ient. The following were particulars of a test which was carefully ıade on the same lathe:

NGOT

Carbon.....0.6 per cent
Manganese.....0.6 per cent
Yield.....19½ tons
Breaking.....45.2 tons
Elongation.....17½ per cent

OTOR LATHE AND JOB RUNNING LIGHT WITHOUT CUT, ABOUT 4.4 H.P.

Face-plate running at.....8 r.p.m.
Diameter of object turned.....13¼ in.
Cutting speed in ft. per. min.....28
Depth of cut.....⅛ in.
Feed.....⅛ in.
Sectional area of cut.....0.1406 sq. in.
Total horsepower.....31.4 = 117 tons per sq. in.
Horsepower for cut only, neglecting increased friction due to load.....27.0 = 101 tons per sq. in.
Gross horsepower for 0.1. sq. in. section at 1 ft. length.....0.8
Horsepower for 0.1 sq. in. section at 1 ft. length, for cut only as above.....0.685
Efficiency.....86 per cent
Gearing.....30¼ to 1

Evidently there would be a further loss by increased friction due to load which would reduce the efficiency below 86 per cent, but a corresponding reduction would have to be made on the pressure of the chip which would fall below the figure of 100 tons, upon which Mr. Adamson had based his calculation.

Mr. Adamson had expressed difficulty in understanding the reasoning intended to be conveyed by Fig. 4 and Table 2 and thought that the charge of one shilling per hour for a machine costing £1000 did not include many items of expense which should be taken into consideration for any comparison of machines. The author had stated (Par. 27) that there were many other variables which had to be taken into consideration, and not wishing to complicate the line of argument, had thought it best to deal only with the three principal factors and to keep the curves shown in Fig. 4 as few

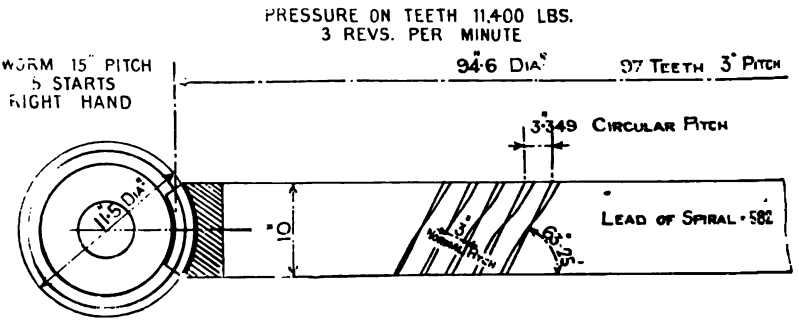


FIG. 30 WORMWHEEL

as possible. Curves might have been introduced for cost of power, floor space, supervision, etc., which would have complicated the figure, and would have required much explanation. The author in this case, as in other cases in the paper, tried rather to indicate a line of reasoning to be followed than to give cut-and-dried results to answer for every condition. The machine charges were purposely kept low, so that any criticism would be in the direction to accentuate the argument, but it must not be forgotten that the larger and more expensive the machine the more likely was it to be run on day and night shift and thus reduce the charges per hour.

The argument advanced was so simple and obvious that Mr. Adamson had probably looked for some deeper meaning where nothing of the kind existed. The author had found in his experience that not only was it important to urge to some persons the

of modern improvements, but that it was also important to rain others from carrying such ideas to excess.

urther information regarding the wormwheel was shown in Fig. 30, this was only one case out of many in the author's own experi-e. The thread of the screw in the back center of the lathe referred n Fig. 10, was a quarter of an inch in pitch.

legarding the life of the drills under the conditions named in Table t was very desirable to grind drills before the edge had much more n lost its sharpness; nothing detracted more from the life of a l than using it after the points on the outside had lost their edge. his were done, not more than 0.01 in. need be ground off; for each ıding the drill should penetrate 150 in. Some workshop results ich showed extraordinary lasting properties at slower rates were en in Table 16.

TABLE 16 SOME WORKSHOP RESULTS

Size Drill, in.	R. p. m.	Feed, in. per min.	No. of Holes Drilled	Depth of Holes, in.
¾	510	6.05	45	3
1¼	206	3.875	40	5
0.92	300	3.8	213	2½
0.92	300	2.75	2450	1½
	320	3.00	221	1

he author thanked Mr. Addy for his commendation for having ided exaggeration in his paper, and while not disclaiming this ıpliment, he would draw attention to Table 5 where a tool was ed to have removed 7½ tons of 40 tensile steel in 82 hours with-grinding. The tool failed in the end by breaking owing to deep groove cut into it by the continual wear of the cutting. s test was somewhat unique in its way, as it was rarely that h a quantity of material was removed off one piece of work.

With regard to Mr. Addy's remarks on the advantage of not alto-her losing sight of carbon tool-steel, the author would draw attention to where it was stated that it was sometimes policy run slower rates with a cheaper tool. Further, where keen cutting ges were required for finishing tools the highest classes of carbon-el still held their own. The percentage given by Mr. Addy as of carbon tool-steel to high-speed steel, would, of course, vary ording to the class of work.

SYMPOSIUM ON GEARING

No. 1292*a*

TOOTH GEARING

By J. D. Steven, Birmingham, England

A. M. I. Mech. E.

bject of gearing is one which has received a considerable
of attention in recent years. Numerous articles have ap-
the technical papers, and suggestions have been made on
methods of cutting wheels, and on various modifications for
ns of teeth. The views expressed have not so far resulted
arked uniformity of opinion, and it is with the hope of
uch discussion that will lead to more uniformity that this
been written. The cycloidal shape has not been considered,
ute being in most general use.

dern Necessity for Accuracy. The following remarks are
to apply more particularly to gears of comparatively fine
rom say the smallest up to 4 diametral pitch or 3 diametral
r, although they may be capable of wider application, it
the author that the advent of the automobile, and to some
the steam turbine, has created the necessity for the finer
eing cut with greater accuracy than was considered either
or necessary up till 12 or 15 years ago. The automobile
urer has steadily raised his standard of quietness since the
were fitted to, the author believes, a Panhard car in about
896, until the present time; and during the last two years
it of the piston-valve engine has necessitated all other parts
de practically noiseless. With the steam turbine also there
a demand for smooth-running high-speed gearing to drive
achometers, etc., and now that attention is being given to
ion of using gearing on turbines to reduce the speed for
ulsion, there is likely to be an increased demand for accurate
the near future.

d at the meeting of The American Society of Mechanical
with The Institution of Mechanical Engineers, Birmingham,
July 1910.

3 *Gear-Cutting Machinery.* A vast amount of ingenuity ha been expended in the design of machines to produce gearing of th accuracy required, and the work turned out from many of the could hardly be improved upon. In considering the merits of the machines, however, one is inclined to ask why so many of the should cut forms of teeth more or less different from each other. (the whole, the differences are slight, but they are often suffici

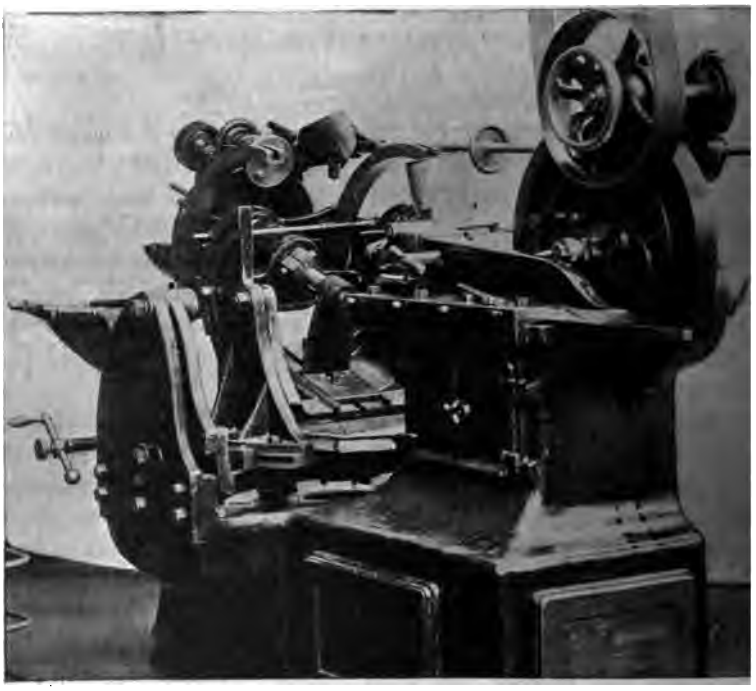


FIG. 1 No. 2 FULL AUTOMATIC BEVEL PLANER (BILGRAM)

to prevent smooth rolling between the gears. It may be of inte to briefly consider a few of the principal makes of gear-cutting chines, particularly with regard to this variation in tooth shape duced by them, and their ability or otherwise to produce teeth of same shape.

4 *Bevel Gears.* For cutting bevel gearing there is little doubt the generating machine has largely superseded the type wor with a former.

Machines with Formers. These machines produce not a true form tooth, but one which is adjusted to do away with undercut, like that duced by a Brown and Sharpe rotary cutter. The formers are to ne extent a source of trouble, as slight differences in their shape l cause difficulty when different numbers of teeth have to roll h each other. The advantages of these machines are that they very stiff in construction and therefore speedy, and that a strong n of tooth is produced, which rolls in many cases quite satisfac-

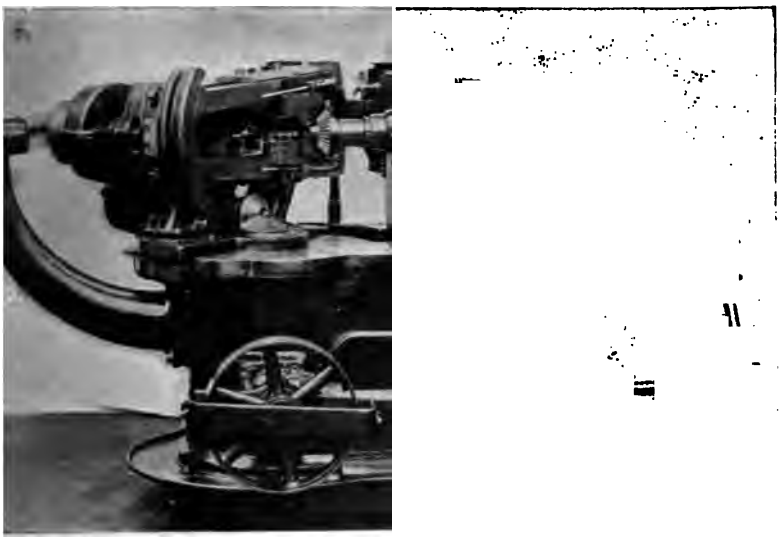


FIG. 2 AUTOMATIC BEVEL PLANER (GLEASON)

ly enough, particularly for differential pinions, which do not run tinuously, or at a high speed. The first cost, too, is generally than that of a generating machine.

Bevel Generating Machines. The best known at present are Bilgram bevel-planing machine (Fig. 1) and the Gleason generat- bevel planer (Fig. 2). These machines are capable of cutting all rs within their capacity with true forms of teeth so that they will satisfactorily with each other. Increased angle of pressure can produced, and proportions of teeth (depth, etc.) altered at will either make of machine. Generally speaking, the Gleason ma- ne is the speedier, and the Bilgram produces, perhaps, the finer finish. om the purely machine shop point of view the first cost is high,

Fig. 3 Spur-Gear Rotary Cutter

Fig. 4 Hobbing Machine (Humeage, [illegible])

Fig. 5 Gear Shaper (Fellows)

and they require skilled attention to keep them in thorough order, so that a simpler type of tool might be more suitable where such skilled attention was not available. The gears from these two machines can be made interchangeable with very little trouble, and a high degree of accuracy can be attained.

7 *Spur Gears.* For cutting spur gears, there are three principal methods, namely, by rotary cutters, generating planing, and hobbing. For the first method the Brown and Sharpe machine is probably the best known (Fig. 3), and with cutters accurately made to Messrs. Brown and Sharpe's formula, exceedingly satisfactory gears are produced. However, all gears having below 30 teeth, if made to the Brown and Sharpe figures, are undercut below the pitch line to provide for clearance of the engaging teeth, as will be seen in the diagrams later on, and as undercut cannot be produced with a rotary cutter, an amount of adjustment is required in the shape, which affects the teeth rolling with those produced by other methods. If the standard tooth shape can be so altered as to allow of a reasonably small number of teeth being cut without alteration to the true form either above or below the pitch line, there is no reason why the single-cutter method should not continue to hold its own with any others for some time to come.

8 *Spur Generating Machines.* Among generating machines the Fellows gear-shaper (Fig. 5), and the Reinecker spur-gear planing machine (Fig. 6), are well known. The Fellows forms the teeth with a cutter which corresponds to a pinion of the same pitch as the gear being cut. A very satisfactory tooth is so produced, but with the standard form of cutter metal is removed below the pitch line and the tops of the teeth are left practically square, so that they do not roll satisfactorily with those cut by the Brown and Sharpe methods. An advantage in this machine is that gears can be cut close to a solid flange, sufficient clearance only being necessary to allow cuttings to get away from under the tool. In the author's experience the Fellows machine hardly produces work so quickly as the rotary-cutter method.

9 The same reasons as the above prevent teeth cut on a Reinecker planer from rolling with those cut on a Brown and Sharpe machine. The Reinecker is, however, a very ingenious machine, planing the teeth with a flat-sided cutter exactly as a bevel planer does, and the angle of pressure can be varied in particular cases. Its great disadvantage is the time required to cut a given gear, which is about double that taken on a Brown and Sharpe (Fig. 7).

10 *Hobbing Machine* (Fig. 4). The hobbing process, which of course, really a generating one, has of late years come much i favor, and with well made hobs very satisfactory work can be do at least as rapidly as on a Brown and Sharpe machine. In a pa read before this Institution by Mr. Thomas Humpage at the Sum Meeting in July 1908, some of the advantages and disadvantag this method are stated. The principal advantages claimed are s

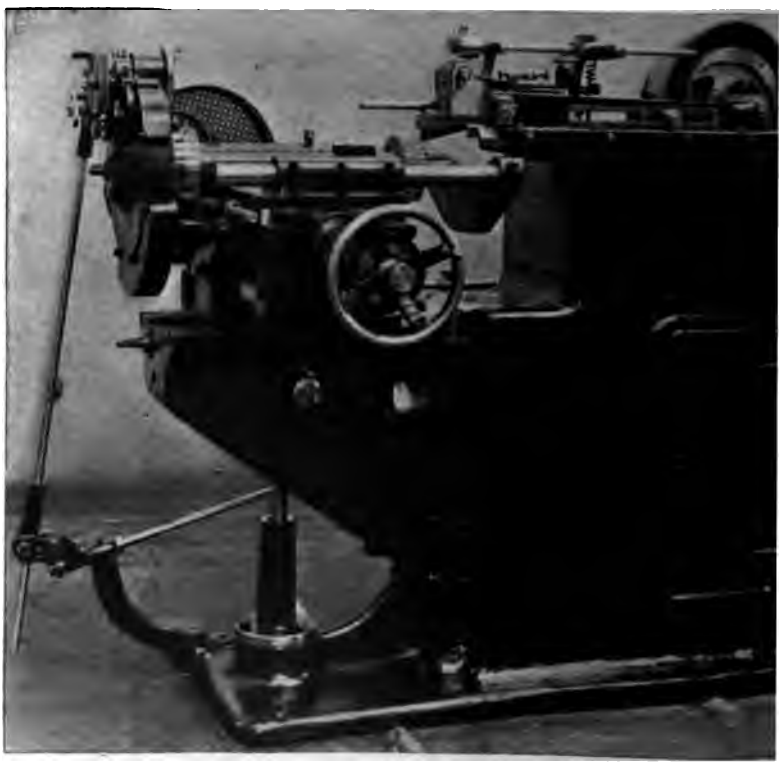


FIG. 6 SPUR-GEAR PLANING MACHINE (REINECKER)

and greater accuracy; and the disadvantages, the production of on the gear teeth due to the spacing of teeth in the hob, and a tend to leave their points too thick. The first objection causes tro in certain cases, but the last objection is hardly a real one, as it be overcome by slightly modifying the shape of the hob tooth.

11 The principal difficulty from the machinist's point of vie that unless he can produce gears from a hobbing machine to

with others, its use is at once limited. It is fairly easy to make a hob which will cut teeth of a Brown and Sharpe shape, but these will not then roll with those cut by generating methods, so that a double or even larger stock of hobs would have to be kept to meet all cases. This alone is a serious item of expense in days when most tools are made of high-speed steel, costing anything over 1*s.* 6*d.* per lb.

12 *Worm-Gearing Machines.* Worm gears are usually made by cutting the worm on a lathe or special thread milling machine, and the wheel by feeding a taper hob past its diameter at the proper

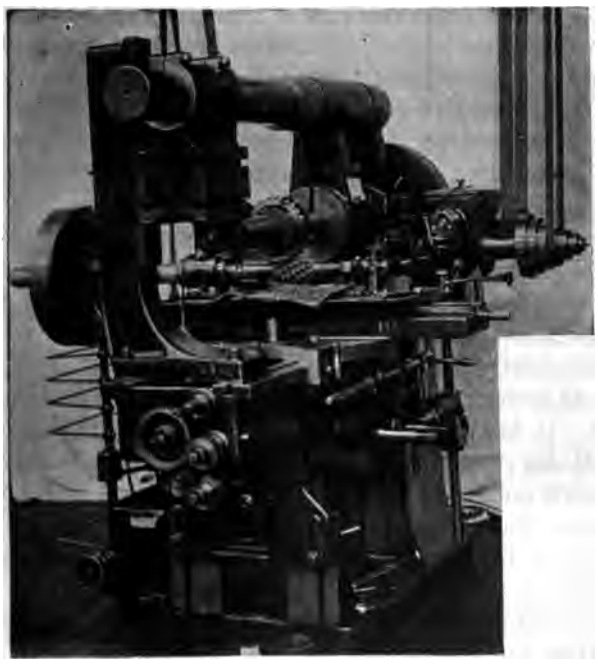


FIG. 7 UNIVERSAL GEAR CUTTER (REINECKER)

working centers. In some cases a straight hob is used which is fed into instead of past the wheel. In neither case is the shape of tooth affected by the machine used, so that the importance of the merits of different machines from this point of view does not arise.

13 *Advantage to Machine Shop of Uniform Tooth.* It is evident from a brief consideration of a few typical gear cutting machines, that any change in tooth proportions which would enable any of them to be used with equally successful results, would be welcomed in many machine shops. At present it is often the case that two or

three machines can stand idle, while the heap of blanks grows larger instead of smaller round others which have produced the first few gears, and must cut the remainder for the sake of interchangeability. Before advocating a change in the standard form of tooth, however, it is necessary to carefully consider it as affecting (*a*) the supporting and housing of the gears, (*b*) the strength of the teeth, and (*c*) the amount of contact surface and any other proportions which go to make a smooth-running wheel. Unless we can satisfy the user of the need for change, the machinist's troubles are unlikely to influence opinion as to the best form. In speaking of users, it may be interesting to note here that of six leading automobile firms who were asked their opinion on the standard tooth, two believed a change necessary, two gave a qualified reply to the effect that they sometimes departed from Brown and Sharpe shape, and that they always thought there should be more cutters to a set, and two others were satisfied with the present state of affairs.

14 As it is obvious that we must do away with undercut in our tooth if we are to cut gears at all with a single milling cutter, and get the full strength where it is required, namely at the root, an increased angle of pressure seems to be the first alteration desirable. But increased angle of pressure increases the load on the bearings, which, carried to an extreme, would be a substantial reason for remaining as at present. If, however, an increase from 14½ deg. to say 20 deg., or at most 22½ deg., will satisfy the conditions, there are few cases where bearings could not be made to safely take a load greater by 5 per cent or 6 per cent than before.

15 Again, if the first alteration is to increase the pressure angle, we at once increase the strength of tooth by broadening it at the base, so that there can be no objection on this score. If then, as they appear to the author, these are the two slightly extraneous points likely to arise in considering the effect of a new shape, they are not difficult to dispose of, and there is no reason why the matter cannot be considered solely with a view to arriving at the best shape for general purposes.

16 *Models of Teeth.* In order that the subject of tooth dimensions and proportions might be examined, there has been recently made at the author's works a number of cardboard models with teeth carefully laid out full size. A table is used having a straight edge fixed to one side, and against this is laid a cardboard rack. A segment of a pinion of twelve teeth is fixed on a center at the proper working distance, and a sheet of glass laid over the whole. By moving the rack along

aight edge the points of engagement of the teeth can be most :torily observed. The rolling of the segments with each other ıged by fixing them on pins at the proper centres. They can ɜ moved round under a glass plate and their contact, etc., in ıt positions, noted.

The diagrams, Figs. 8–14, are produced from photographs ı models. In all the diagrams the principal parts of the teeth tered thus: A, addendum points; P, pitch line; B, base line; :king depth; D^1, whole depth. Table 1 shows particulars of odels which were used. The large pitch was adopted so ıe differences in the various forms could be more clearly seen.

TABLE 1 DETAILS OF GEAR TEETH

	14½°	14½°	20°	20°
	ORDINARY	STUB	ORDINARY	STUB
›f teeth in pinion	12	12	12	12
itch	12.1661	12.1661	12.1661	12.1661
l pitch	0.2582	0.2582	0.2582	0.2582
neter	46.471	46.471	46.471	46.471
ameter	54.216	52.553	54.216	52.553
›, diameter	44.988	44.988	43.668	43.668
lepth, diameter	38.726	40.389	38.726	40.389
›th, diameter	37.509	39.172	37.509	39.172
thickness	.....	6.083	.....	.....
ıickness	.....	6.066	.....	.....
m	3.872	3.041	3.872	3.041
m	4.481	3.650	4.481	3.650
	8.353	6.691	8.353	6.691

Brown and Sharpe Tooth. Fig. 8 shows a 14½-deg. angle rack gaging with it a 12-tooth pinion laid out correct to figures, and o correction for undercut. This is, of course, the tooth which be generated by a hob or by other form of generating machine tool was not altered to prevent the base of the tooth being so ıed. From this diagram the amount of undercut necessary in a :h pinion to enable it to clear the points of the rack teeth is evident, and the sudden change in form of tooth just below :ch line is somewhat startling to any one who has not so far e necessity or inclination to consider the subject.

FIG. 8 TOOTH 14½-DEG. ANGLE OF PITCH AS PRODUCED BY GENERATING PROCESS (BROWN AND SHARPE)
FIG. 9 TOOTH PRODUCED BY ROTARY CUTTER (BROWN AND SHARPE)

FIG. 10 GENERATED TOOTH IN MESH WITH SINGLE CUTTER TOOTH (BROWN AND SHARPE)
FIG. 11 TEETH AS IN FIG. 10 BUT IN DIFFERENT POSITION

FIG. 13 FULL DEPTH 20-DEG. ANGLE OF PRESSURE. TOOTH IN MESH WITH RACK
FIG. 14 STUB 20-DEG. ANGLE OF PRESSURE. TOOTH IN MESH WITH RACK

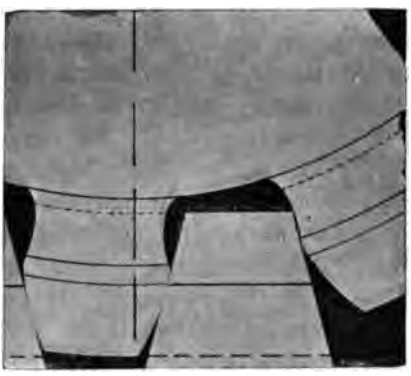
A Addendum points
P Pitch line
B Base line
D Working depth
D^1 Whole depth

FIG. 12 STUB TOOTH 14½-DEG ANGLE OF PRESSURE IN MESH WITH RACK

FROM FIG. 8

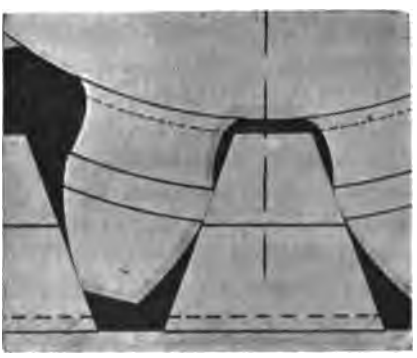
FROM FIG. 9

FROM FIG. 10



FROM FIG. 12

FROM FIG. 13



FROM FIG. 14

15 ENLARGED VIEWS OF SOME TEETH IN FIGS. 8, 9, 10, 11, 12, 13, 14

tted lines are Center Line of Wheels and at Right Angles to Racks

19 The rack tooth immediately to the left of the center line is seen with its point just meeting the pinion below the pitch line and shows why the clearance is required.

20 In motor-car back-axles, where it is quite common to have 14 or even 12 teeth in the bevel driving pinion, this weakening of the base of the tooth is of increasing consequence, as the tendency increases to have a higher horse-power than the nominal. If the gears are cut on a generating machine the tooth can only be strengthened by adopting a greater angle of pressure.

21 Fig. 9 shows the standard Brown and Sharpe tooth as it would be produced by a single circular cutter. Here the flanks of the tooth are radial and give greater strength at the base. The amount of rounding off on the rack tooth is seen in this diagram, this being required, of course, to clear the part of the pinion tooth below the pitch line. With a pinion as shown, it is obviously necessary to round off the points, not only of rack teeth but of the teeth of gears containing any larger number of teeth than the pinion has when they are required to run with it. The amount of this rounding is, as stated in Messrs. Brown and Sharpe's own treatise on gearing, to be determined more by experiment than by rule. It introduces an uncertain quantity into the work of laying out gages, and certainly removes, coupled with the radial flanks, a great part of the proper form of the tooth.

22 Fig. 10 shows an attempt to run a generated gear with a Brown and Sharpe standard. It can at once be seen that the point of the generated tooth on the right-hand pinion is overlapping the other and would have to be considerably rounded, in an actual gear, before it could be made to run.

23 Fig. 11 shows the same two gears in a different position with relation to each other. The points of the outer teeth on the Brown and Sharpe pinion are some distance away from the flanks of the generated gear, so that the load is all on the one tooth.

24 In Fig. 12 is shown a form of short or stub tooth engaging with a straight-sided rack, the angle of pressure being 14½ deg.; while this appears to be, and to some extent is, stronger than the Brown and Sharpe tooth of standard depth, there is still undercut, and this will be required in stub teeth in any proportions so long as the 14½-deg. pressure angle is retained.

25 *Increased Angle of Pressure.* Having seen the limitations of the tooth with 14½-deg. pressure angle, it is worth considering whether an increased angle will result in a better form for universal adoption. While, as already pointed out, a slight increase in bearing pressure

cannot be a very serious objection in most cases, there is no object in increasing the angle, and consequently pressure, more than necessary.

26 In Fig. 13 is shown a tooth of standard depth, but with an angle of pressure of 20 deg. It will be noted that the undercut is very slight, so that it would disappear in a gear of a few more teeth than the pinion shown.

27 We can now increase the angle by a few degrees, or endeavor to dispose of the remainder of the undercut by other means. Having reached the required result so nearly by an increase of only 5½-deg. angle, and consequently an increase of about 5 per cent load on the bearings, it may be better to leave this proportion as it is; or, on the

TABLE 2 CONTACT ON A TWELVE-TOOTH PINION (APPROXIMATE FIGURES)

Description of Gear	Length of Undercut Curve from Interference Point to Working Depth	Length of Working Curve		Total Length of Tooth Curve	Percentage of Working Curve to Total Tooth Curve
		Addendum to Base Circle	Reduced Due to Undercut Interference		
12 teeth 14½-deg. angle of standard depth	5.630	5.050	4.640	8.260	56.17
12 teeth 14½-deg. angle of pressure stub depth	2.560	4.060	3.840	6.400	60.00
12 teeth 20-deg. angle of pressure standard depth	2.680	5.900	5.750	8.430	68.20
12 teeth 20-deg. angle of pressure stub depth	1.660	4.875	4.875	6.535	74.59

other hand, it may be better to still increase the angle, and leave the other proportions alone. The author is inclined to favor the former alternative.

28 In a paper read by Wilfred Lewis before the Engineers' Club of Philadelphia, in 1900, an increase of pressure angle to 20 deg. or even 22½ deg. is advocated, but the depth remains unaltered. In a pamphlet published by the Fellows Gear Shaper Company in 1907, a 20 deg. is advocated, with a short or stab form of tooth. Here we have a difference of opinion in two quarters where consideration has been

given to the subject, and so long as such differences exist it is difficult for the ordinary user of gearing, with probably but a slight interest in such questions, to decide on the best form for his work.

29 A list giving the amount of contact with each form of tooth, and various numbers of teeth of each form, would be somewhat lengthy, but Table 2 giving the contact on a 12-tooth pinion, of dimensions as in Table 1, may be of interest.

30 It is well to remember that in teeth such as the Brown and Sharpe 14½-deg. angle, the larger the number of teeth running together the less is the contact, owing to the rounding of the tops, and whereas when a tooth is used of such proportions that the correct shape requires no alteration, there is no decrease in contact with larger numbers of teeth.

31 It will be seen from Table 2 that in the teeth under consideration those with 14½-deg. pressure angle would have rather more contact than the 20-deg. stub form, were it not that the undercut extends above the base line, and so interferes with the contact. As at about 25 teeth the proper working curve will not be interrupted in this way, its length with 14½-deg. angle, and ordinary depth, is 0.175 inch greater than with 20-deg. and stub depth. In small numbers of teeth the stub contact is actually the greater, and in all numbers of teeth the proportion of working curve to total is much greater.

32 Fig. 14 shows a pinion with such teeth in mesh with a rack. This tooth is advocated by the Fellows Gear Shaper Company, but their method of fixing the depth seems unnecessarily complicated. They advocate having a 4-pitch tooth with 5-pitch depth, a 5-pitch with 7-pitch depth, a 6-pitch with 8-pitch depth, and so on; the depth in every case but the 4-pitch being that of a pitch No. 2 finer.

33 As module and various odd pitches have to be dealt with, a more general method of fixing this dimension would be, in the author's opinion, an advantage, and to take one quarter of the circular pitch as the addendum in each case, is a much simpler thing to remember. The difference is not much between this and the Fellows depth. The following figures show what the difference is on a 6-pitch gear:

	Fellows ⅘ Pitch	Author Circular Pitch ÷ 4
Addendum	0.125	0.1309
Dedendum	0.1562	0.1570
Whole depth	0.2812	0.2880
Thickness	0.2617	0.2618

r a difference of 0.0068 in the whole depth. What has been said pplies, of course, equally to either spur or bevel gears.

34 *Worm-Gearing.* While no investigation can be complete which gnores this important form of gearing, the author feels that it is uite impossible to deal with it in the scope of a short paper. So nany worm gears are now being used in automobile work, and so nuch difference of opinion exists as to efficiency, angles of pressure, globoid and straight worms, and other points, that it is to be hoped he latest practice may be the subject of a paper by someone fully able o deal with it, at an early date.

35 *Conclusion.* The author is well aware that this paper contains nothing very new on the proportions of gear teeth, but, as stated in the beginning, his object has been to bring the subject before the members, so that if possible some uniformity of opinion may eventually result. Such uniformity would undoubtedly be most welcome to everyone who has either to cut or use gearing to any extent.

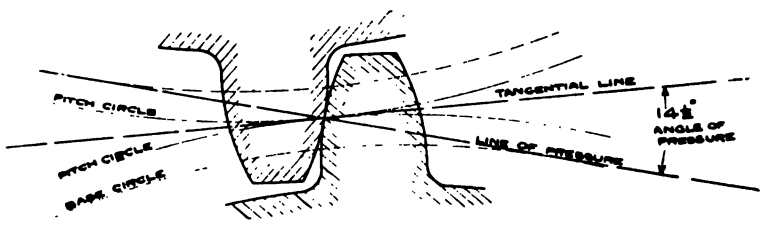


FIG. 16 THE ANGLE OF PRESSURE OF A PAIR OF GEARS

36 He also feels, as stated in the early part of this paper, that conditions have so radically changed during the last few years, there is every reason to consider the question now with an open mind, and in the fullest possible manner. If a new form of tooth is desirable, it is his opinion that the stub form with 20-deg. angle of pressure would be a change in the right direction, because

a It can be used right down to 12 teeth in its true form, and cut on either a single cutter or generating machine.

b It is altogether a stronger form than that most commonly used at present.

c A very large proportion of its face does useful work.

d The possible objections on the score of less contact and greater bearing-pressure are so slight as to be nearly negligible.

37 Thanks are due to those firms who have so kindly replied to inquiries regarding their experience and practice, and to the staff of Messrs. E. G. Wrigley and Company, for their assistance in preparing and photographing the models of gear teeth.

38 *Definition of the Angle of Pressure.* The angle of pressure of a pair of gears (Fig. 16) may be defined as the angle made by the line of mutual pressure with the common tangent to both pitch-circles at their point of contact.

No. 1292*b*

:RCHANGEABLE INVOLUTE GEARING

By Wilfred Lewis, Philadelphia, Pa.

Member of the Society

is paper was prepared at the request of the Committee on of The American Society of Mechanical Engineers as the on to the discussion upon the need of a standard or stand- ars to be considered at the meeting with The Institution of al Engineers in July 1910. By way of explanation, it may be its author is chairman of a committee on Standards for Gears, appointed about a year ago by the president of The Society of Mechanical Engineers to investigate the subject of geable involute gearing, and to recommend, if found desir- andard or standards. This paper, however, is not to be l as an expression of the opinions of the other members mittee, except where so stated.

er more or less unsatisfactory experience with cycloidal investigated about twenty-five years ago the subject of earing with the object of determining upon a system, for Wm. Sellers & Company, with which I was then connected. tions imposed called for a system applicable to any number between a 12-tooth pinion and a rack, without change in addendum which had always been made 0.3-pitch for the eeth, hitherto used almost exclusively by them.

ound that the involute forms then in vogue were confined to of $14\frac{1}{2}$ deg. and 15 deg. with an addendum equal to the or about 0.32-pitch. This long addendum with such small naturally gave rise to interference between racks and less than 30 teeth, and rather than modify the involute ally recommended the adoption of a pressure angle of 20 the same time, I was well aware of the fact that even this was not sufficient to prevent interference between a 12-

d at the meeting of The American Society of Mechanical Engi- h The Institution of Mechanical Engineers, Birmingham, uly 1910.

toothed pinion and a rack, but for such pinions and the gears of 60 teeth or less, with which they commonly engaged, I believed the interference would not be noticeable in practice. I was strongly tempted to go further and fix upon an obliquity of 22½ deg., but 20 deg. then appeared such a radical departure from common usage that the advantages of the greater angle were dismissed as being possibly more theoretical than real.

42 The 20-deg. system with an addendum of 0.3-pitch has now been in use by Wm. Sellers & Company for twenty-five years and has given satisfaction in a general way, although the interference referred to has been more or less noticeable on 12-toothed pinions. I reviewed this matter ten years ago in a paper read before the Engineers' Club of Philadelphia, advocating an obliquity of 22½ deg. and suggesting as a much-needed reform in engineering practice the consideration of uniformity in interchangeable gearing. I then pointed to the action of the Franklin Institute more than thirty years earlier, which inaugurated a standard system of screw threads and expressed the hope that by the interchange of opinions an agreement among engineers might be reached leading to the gradual disappearance of needless diversity in the forms of gear teeth.

43 Nothing in this direction had been done however, when the subject of interchangeable involute gear-tooth systems was brought to the attention of The American Society of Mechanical Engineers in a paper by Ralph E. Flanders presented in December 1908. A number of systems in general use were analyzed and their merits discussed from various points of view and the desire expressed that the Council be petitioned to appoint a committee to investigate the subject of interchangeable involute gearing and, if found desirable, to recommend a standard or standards.

44 In answer to this petition the Council voted in January 1909, that the President appoint a committee of five members to formulate standards for involute gears and present the same to the Council. Without anticipating in any way the conclusions of this committee yet to be formulated, if indeed an agreement be possible, I believe it will be helpful to give publicity to the line of investigation upon which we have embarked and thus obtain the benefit of such criticism or encouragement as it may provoke.

45 At the first meeting of the committee in June 1909, it was decided to obtain an expression of opinion from the manufacturers of gears and gear cutters and later in October the following circular letter was sent out:

Dear Sir:

A committee of The American Society of Mechanical Engineers has been appointed to consider the subject of standards for interchangeable involute gears, and would like to have as much light upon the subject as can be given them by the manufacturers.

Without limiting in any way the type of gears to be used for any special service, it is believed to be desirable that some type should be known as standard so that any gears of that standard may run together and be perfectly interchangeable.

The committee is, therefore, interested to know the extent to which involute gears are modified in your practice to avoid interference, and it would be pleased to have your ideas as to what, in your opinion, should constitute standard interchangeable involute gears. Any suggestion you may be pleased to offer will be very much appreciated.

Yours truly,

WILFRED LEWIS, *Chairman*
HUGO BILGRAM
E. R. FELLOWS
C. R. GABRIEL
GAETANO LANZA

Committee on Standards for Involute Gears

46 In response to the circular letter above referred to, about one hundred answers were received, expressing more or less interest in the subject and giving more or less conflicting preferences and conclusions.

47 One correspondent said he would hail with delight any system whereby complete interchangeability could be attained on gears running without noise up to 1000 ft. a minute, as among automobile manufacturers noiseless gearing was always the chief end in view.

48 It is undoubtedly true, as pointed out by other correspondents, that perfect cutters do not necessarily produce perfect gears and that close attention must be paid to the setting of the cutter, proper indexing, speed, feed, etc., and from the extent to which the present 14½-deg. system is established, it has been argued that even if the pressure angle of 14½-deg. were not the most desirable, it would be better for the sake of the established practice to let it alone. Quite a number share this opinion and argue against the recommendation of a standard which may simply add another system to those already in use.

49 It may be said in reply that the chief advantages of involute gearing over cycloidal gearing which it has pretty generally displaced are the comparative simplicity of the involute curve and a slight variation in center distances not permissible in any other system of gearing. Despite the difficulty of securing general recognition for

any system of interchangeable gearing, I believe the committee should investigate and report upon some ideal standard or standards.

50 Attention is called by a number of correspondents to the increasing number of gears cut by the hobbing process and the difficulty of making such gears interchangeable with certain cut gears, thus indicating the hobbing principle as the first principle to which all cutters should conform, the rack being the basis of all generated gears. It is admitted that hobbed gears can be used interchangeably with gears cut by certain other processes, but some doubt is expressed of the possibility of realizing an interchangeable system using pinions with a small number of teeth and teeth of reasonable length without resorting to some modification of the involute curve. The opinion is freely expressed that if such modification becomes necessary the method should be known and clearly defined, so that makers of gears can adopt it and, if necessary, make their own cutters.

51 As pointed out in Mr. Flanders' paper and as mentioned repeatedly by our correspondents, the most desirable quality in gearing and the one by which it is almost universally judged, is quietness and smoothness of running. Next to this come strength, durability and permanence of form, and upon the last, of course, depend continued quietness and smoothness of action. Friction and journal pressure are of less importance, but still worth considering, and before reaching any conclusions from theoretical considerations alone, we propose to determine if possible, in a practical way, the relative advantages of some of the systems in common use and, with these, other systems to which we are disposed to give favorable consideration.

52 It is understood that the Institution would be pleased to have the coöperation of the Society in the work they have in hand looking to a determination of the friction in the transmission of power by gearing. In this connection we have been reminded of a suggestion of Prof. J. Burkitt Webb of Stevens Institute of Technology made soon after the publication of the Sellers' experiments upon gears reported to our Society in 1885. In these experiments an attempt was made to measure the friction loss between the teeth of a pair of spur gears, but the apparatus used, made originally for testing the friction of worm gearing, was not delicate enough for the purpose and the errors introduced exceeded, in some cases, the net result.

53 Professor Webb then suggested the possibility of so dividing one of the pair of spur gears to be tested as to make the load on the

ı self-contained. The apparatus which we have designed embod- his idea, thus making it possible to run gears under heavy loads igh speeds with a very small consumption of power. We have provided in our apparatus for an adjustment of center distance means to measure the thrust between centers while the gears are ıing. Of course, the thrust between centers can be estimated closely for involute gears from the pressure angle on the teeth, we anticipate results somewhat in excess of this on account of excess in friction of approach over that of recess, and, if any but lute gears are tested, it will also be interesting to compute from ırimental data the effective obliquities of other systems.

We propose to determine the friction loss under various ds and pressures for wheels and pinions cut to the Brown and rpe 14½-deg. standard, the 20-deg. stub tooth and a 22½-deg. tooth ı addendum of $\frac{1}{8}$ module or about 0.278 pitch. These gears will ested at normal center distance, and also at distances about 1 cent or 2 per cent of the pitch greater or less than this, and an rt will be made to record graphically the noise produced under e different conditions.

We believe that accuracy and permanence of form can thus be ın their proper influence on the reduction of noise. It may take e time to determine the effect of wear, but from the method of ling the teeth and the small amount of power consumed some cation of the tendency of wear can be obtained. All gears tend wear out of shape, and involute gears more so than cycloidal, we recognize as a possibility that this tendency may be checked he deformation itself and also that the loss in friction at different ts of a gear tooth is practically incalculable on account of the ıations in friction for different velocities of sliding.

The experiments we propose should therefore give informa- ı unobtainable in any other way and throw a flood of light on the blem in hand.

As it is quite impossible for any of the committee, who are busy men, to make the experiments here outlined, we have been unate enough to interest, through the intervention of Professor ıza of the Massachusetts Institute of Technology, two of his ergraduates, Messrs. Green and Doble, in making these experi- ıts the subject matter for a graduating thesis. Professor Lanza ed to have the work completed in June so that the results might be ımunicated for discussion at our meeting in England in July but this proved impossible, partly because of the magnitude of the under-

taking and partly of the delay in the completion of the testing machine.

58 The apparatus used in making these experiments is shown in the photographs, Fig. 17 and Fig. 18, and the line drawing, Fig. 19, which gives some of the principal dimensions and shows the knife edges on which the machine rests. The machine consists of a frame A designed to carry a pinion shaft in roller bearings at one end, and a frame B pivoted to it and designed to carry the gear wheels W engaging with a wide-faced pinion P on the pinion shaft. The frame B is held to the

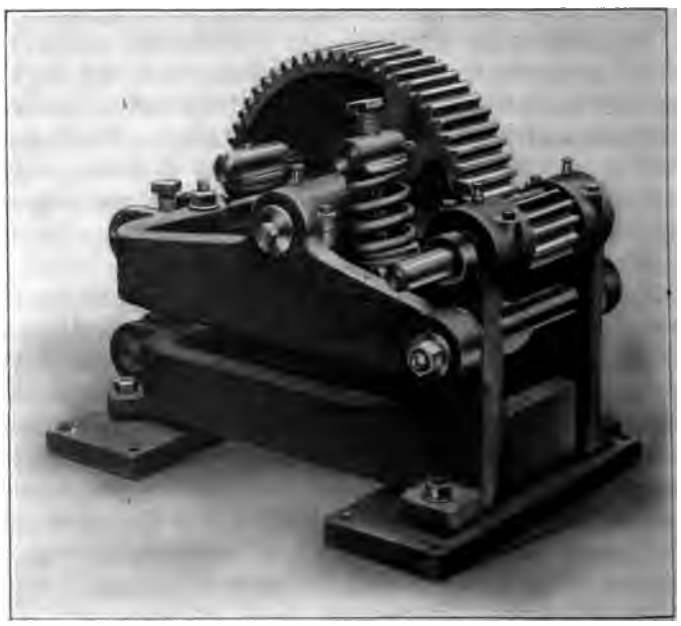
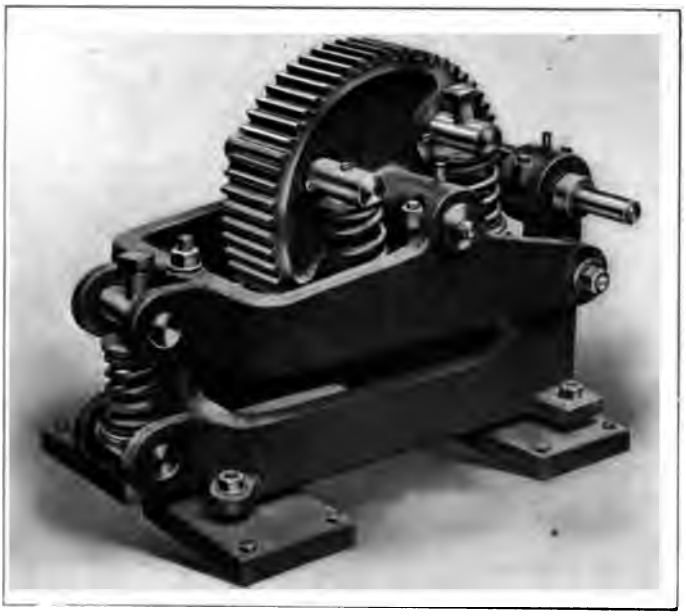


FIG. 17 GEAR TESTING MACHINE

frame A at its outer end by an adjustable clamping bolt C, and provision is made to measure the thrust on centers by means of the spring D acting between the frame A and an adjustable abutment on the frame B. The gear wheels to be tested consist of a central gear with a wide face and two side gears with narrow faces. The central gear carries two heavy cross pins G, which pass through clearance holes in the side gears, and the side gears carry two heavy pins H, which pass through clearance holes in the central gear. Between the projecting

ls of these pins G and H, heavy helical springs S are inserted, upon ich pressure can be applied by means of the set screws K.

59 The pressure of these four springs S is resisted by the gear th, the middle gear pressing against one side of the pinion teeth d the side gears pressing against the other side. The pinion thus comes simultaneously a driver and a driven gear and the power quired to turn it when loaded in this way is only that required overcome the friction of the teeth and whatever resistance there ay be in the gear journals. The latter presumably is very small



IG. 18 VIEW SHOWING ARRANGEMENT OF PIVOTED FRAME AND SPRING FOR MEASURING THRUST

ideed, but provision has been made to measure it by substituting lain cylinders without teeth for the gears and pinion, and running ese under the same journal pressures. By deducting the resistance ue to journals from the total resistance with running gears, the iction of the teeth alone can be determined.

60 In operation this machine is driven by an extension to the inion shaft, carried to bearings several feet distant to permit of mple flexibility. The knife edge directly beneath the pinion rests

upon a permanent support, and the other knife edge is carried upon the platform of a small platform scales. The driving moment in the pinion shaft will therefore be measured by the scale reading at the end of an arm 20 in. long, and by reversing the direction of motion given to the pinion shaft the effect of any initial lateral strain in the driving shaft can be eliminated.

61 Fig. 20 illustrates three types of gearing to be tested by Messrs. Green and Doble, and with these other types may be included later on.

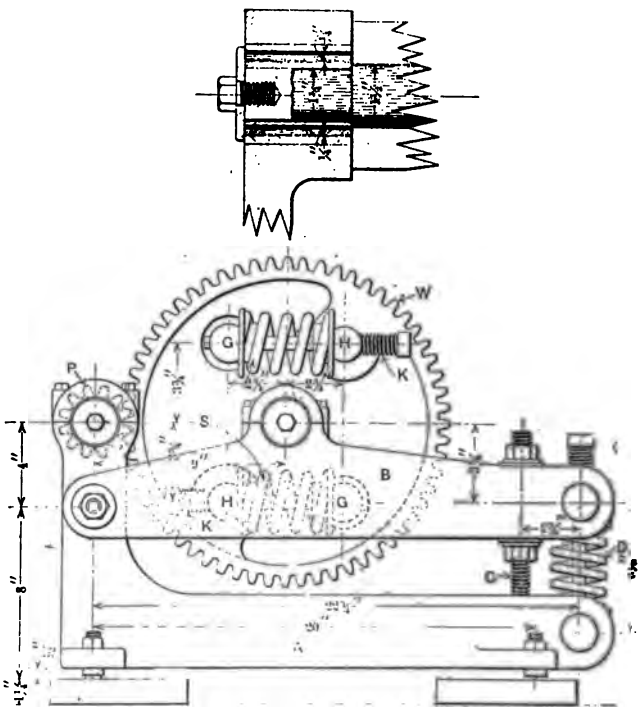


FIG. 19 DIAGRAM OF GEAR TESTING MACHINE

62 Figs. 21, 22 and 23 illustrate a group of involute gears designed by Mr. Bilgram to engage a rack of 15-deg. obliquity, and to demonstrate the possibility of using pinions of ten or even nine teeth with such a rack, provided the addendum can be varied. Without wishing to advocate the use of a variable addendum in interchangeable gearing, it is interesting to note the possibility of making a tentative solution of the problem in this way. A set of these gears has kindly been

nished by Mr. Bilgram for making a comparative test. He has o made a set of models, from which the figures have been photo-ıphed, and referring to them, he gives the following explanation:

63 "While the involute system of gearing has decided advantages er any other, it has the one disadvantage that the faces of the

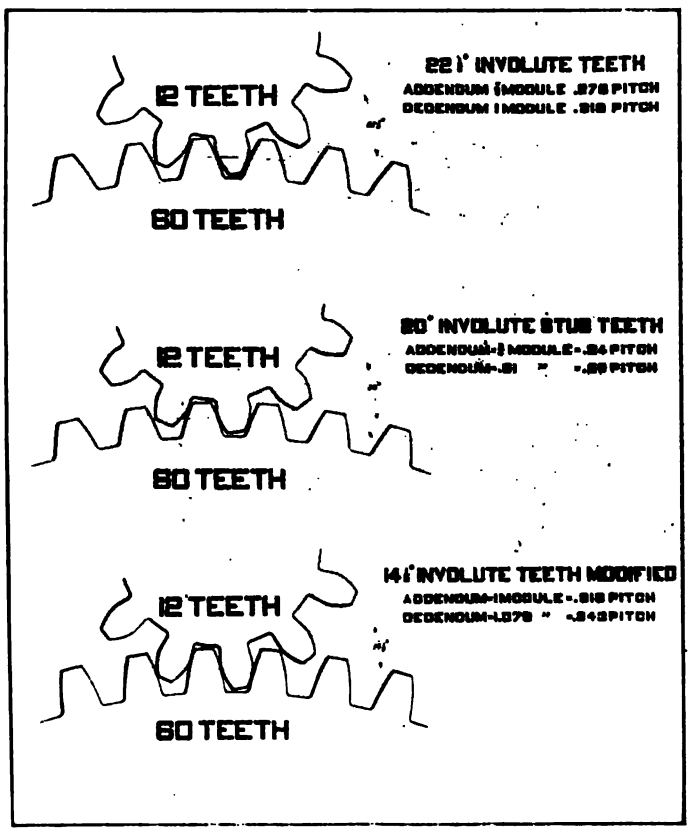


FIG. 20 GEAR TYPES TESTED IN THE MACHINE

ıth of wheels come into interference with the flanks of pinions, if ı latter have a comparatively small number of teeth. Unless the nks of the latter are undercut, the teeth will interlock or at least ısh improperly.

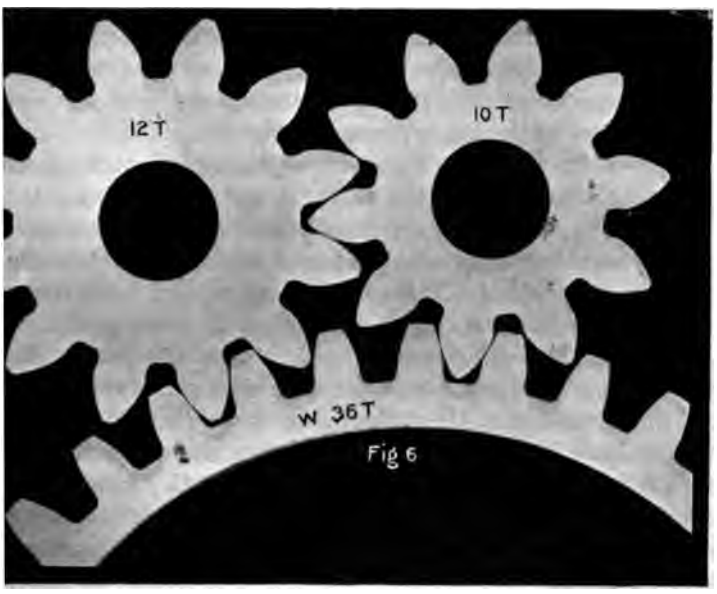
64 "In making a single pair of wheels, a remedy can readily be ıplied. There are two ways in which interference can be avoided,

namely either by increasing the angle of pressure or by shortening the addendum of the wheel. If the latter method is chosen and it is desired not to reduce the working depth of the teeth, it is necessary to add to the addendum of the pinion the amount taken from the addendum of the wheel.

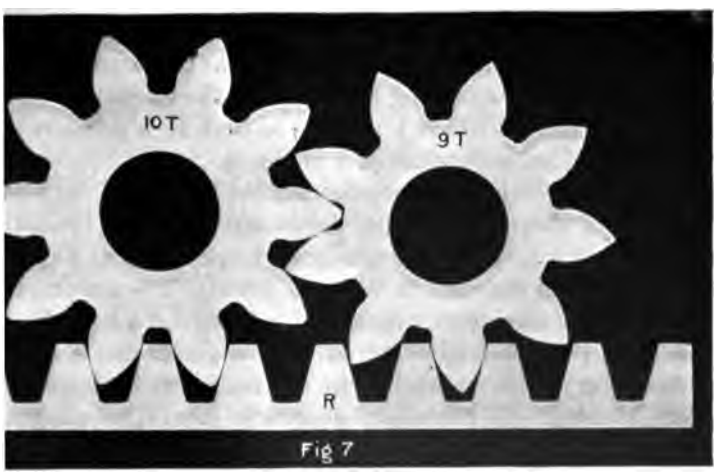
65 "This latter method is out of the question when the problem is given to make an interchangeable set of spur wheels from a rack down to a 12-tooth pinion. This problem may be solved by a combination of both remedies alluded to."

FIG. 21 BILGRAM SYSTEM: PINION WITH UNDERCUT TEETH

66 The method consists of making racks and larger wheels with normal addendum, but increasing the addendum of pinions just enough to prevent the rack tooth from interfering with the flank. The samples presented (Figs. 21 to 23) consist of a rack R and a 36-tooth wheel W, with angle of pressure of 15 deg. and addendum equal to the modulus. The 12-tooth pinion A, generated by a rack, corresponding to rack R, shows the undercutting thereby produced. Obviously this pinion will not work, as so much of the involute is cut away that the path of contact is materially less than one pitch. But there are also shown pinions of twelve, ten and nine teeth, made with increased addenda. These were generated by a rack like R,



BILGRAM SYSTEM: PINIONS WITH INCREASED ADDENDA IN MESH WITH GEAR



BILGRAM SYSTEM: PINIONS WITH INCREASED ADDENDA IN MESH WITH RACK

but with a somewhat greater addendum than that used in generating the wheel W and a somewhat greater cutting depth. If these pinions are then mated with wheels of a large number of teeth, they will not enter as far as with pinions of equal number of teeth and have therefore a slightly less working depth.

67 On this plan may be based a system of involute gearing with a working depth of twice the modulus, and with a moderate pressure angle, 15 deg. in the samples submitted. Pinions of a small number of teeth will have an increased addendum, but a theoretically correct action is maintained. The pinion teeth have a wide base and are strong. One disadvantage in those cases in which pinions with less than about 24 teeth are embraced, is that the center distance is greater than that computed by the usual rule from the modulus and the number of teeth of the meshing wheels. Moreover, pinions will not have the full working depth when meshing with large wheels or with racks, but even in the case of a 10-tooth pinion meshing with a rack, the path of contact exceeds one pitch so that at least for a portion of the action two teeth will be in contact simultaneously.

68 The plan proposed by Mr. Fellows is to use an involute with an angle of pressure of 20 deg. and to reduce the addendum to $\frac{4}{5}$ of the modulus. Such teeth are known as "stub teeth". By this method interference in case of a rack gearing with a 12-tooth pinion is just avoided and in the case of two 12-tooth pinions meshing with each other the path of contact is equal to about $1\frac{1}{3}$ of the pitch.

69 Mr. Gabriel prefers the $14\frac{1}{2}$-deg. standard of the Brown and Sharpe Manufacturing Company and he has prepared a contribution to the discussion expressing his views on the subject.

70 The system which I propose is that of a pressure angle of $22\frac{1}{2}$ deg. and an addendum of $\frac{1}{3}$ of the modulus.

71 I believe that an interchangeable system of involute gearing, to be of the greatest value, should extend from a 12-tooth pinion to a rack, and in the selection of gears to be tested we have chosen a 12-tooth pinion engaging a 60-tooth wheel. The maximum reduction with the maximum strength in a limited space is the problem in gearing that generally confronts the engineer and a ratio of five to one is very often as much as he can realize without sacrificing too much strength. I recognize, of course, that the adoption of a larger number of teeth in the smallest allowable pinion overcomes some difficulties, and that this may be a debatable point, but I do not think any system of interchangeable gearing will be satisfactory which does not include pinions of twelve teeth. The cycloidal

am formerly employed was based upon a 12-tooth pinion, and I ve this number can be retained for the smallest number in an changeable involute system without serious objection. That is, e is better ground for the retention of this minimum number than higher number and when the pros and cons have all been summed here will be no change in this well-established minimum for inter-geable pinions.

Although the experiments made under the direction of Pro-r Lanza are not by any means conclusive, enough has been done dicate that the friction loss in gear teeth is influenced to a greater nt by the length of the addendum than by the obliquity of the em. Theoretically, the friction loss in involute teeth is indepen-of the obliquity and increases with the addendum. The loss in nal friction should vary as the secant of the pressure angle, but latter is also affected by the dead weight on journals which even plain bearings is a small matter, while with ball or roller bearings, a very trifling consideration indeed.

I believe therefore that a pressure angle of $22\frac{1}{2}$ deg. can be pted without fear of reduced efficiency in the transmission of er; that an addendum of $\frac{7}{8}$ module will give an ample arc of on for all combinations of gears between a 12-toothed pinion and ack, and that true involute forms made to these constants will id the necessity for any empirical modifications and give results parable with the best now obtained by such means.

No. 1292*d*

DISCUSSION ON GEARING

/. VERNON[1] said he was present at the meeting as a patient ıt as a doctor. He was connected with a firm of machine-tool s, which had made many long and costly experiments with a f determining, not what he might call academic points in the of gearing, but for the purpose of obtaining a system of gears ould run silently at high speeds. His object in speaking was to at something might be done to discover the points that would lence in gears, as until gears could be obtained which ran silently estion of making them interchangeable could hardly be profit- onsidered. The results of the experiments which his firm ade had been very small in the way of positive knowledge, but ad been very great negatively in the way of teaching them how ttle anybody really knew about gearing. Among the negative were the following: In the first place, it appeared that there) general agreement among engineers or gear makers as to the ıgle of pressure to use; there was no general agreement as to the tions of gear teeth which were the best for quiet running; was no reliable information on the strength of cut teeth made ıdern methods in various materials and running at various ; there was no reliable information at present available on ect of different materials on the strength, the noise, and the f gear teeth. It appeared, in fact, exceedingly doubtful whether possible to make an interchangeable system of gear teeth at quiet running.

rious speakers had stated that the involute system was ect; engineers knew that the epicycloidal system was dead; ıe results of the experiments which his own firm and others ade had proved that involute teeth did not give a quiet gear; picycloidal teeth did not give a quiet gear; that hobbed gears ot quiet, and that planed gears were not quiet. But there was nd of gear which was quieter than all those, namely, the gear "faked" teeth. It now was well known that the gears which he quietest results in running were those on which an empirical

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correction of the tooth form had been made, and so far as he knew the means by which that correction was made were kept secret, and were in the hands of one leading American firm, of which a representative was present at that meeting. When Ralph E. Flanders read his paper before the American society in December 1908, this same representative of that firm practically admitted that the only way to get quiet gears was to make an empirical correction on an experimental basis, and that the best thing for gear users to do was to trust to the experience of that firm, which he (Mr. Vernon) supposed meant to buy their cutters from them. He spoke at that meeting as a member of both The Institution of Mechanical Engineers and of The American Society of Mechanical Engineers, and wished to say that although the greatest credit was due to that firm for having made their investigations and experiments, it was not to the interest of gear users in America and in England that that knowledge should continue to remain in their hands alone. He hoped the remarks he had made would do good by bringing the committee of The American Society of Mechanical Engineers, who were considering gear questions, into touch with the committee of The Institution of Mechanical Engineers, so that investigations might be started with a view to ascertaining what were the corrections which needed to be made to ensure quiet tooth action, and so that such information, when obtained, could be placed in the hands of gear users in both countries.

C. R. GABRIEL.[1] This discussion was prepared at the request of the Committee on Meetings of The American Society of Mechanical Engineers as a contribution upon standards for gears, and is submitted as a personal opinion, rather than a report, as the findings of the committee up to date have not established definite conclusions.

As stated, the committee received in reply to its circular letter, a large number of answers, but few contained comparative data and were largely expressions of theories or opinions, such as most engineers have advanced in explanation of the difficulties arising from improperly cut and noisy gears. The expression "improperly cut" is used advisedly, as from an experience covering a long period of years the writer believes that nine-tenths of all the trouble with noisy gears can be attributed to improper cutting.

As regards the adoption of a standard, the opinion of the writer is that the present so-called Brown and Sharpe standard will hold its

[1] Mem. Am. Soc. M. E.

own against any system for the general run of machinery; and that for many of the cases where special cutters or forms of teeth are used, the benefits of such modifications are more imaginary than real. The answer to the difficulties arising where high speed, durability and efficiency are required, will be found in the substitution of better material and better methods of treating in the hardening process.

The present system is called by some an empirical one, but any carefully worked out system will be so, as practice shows that decidedly better results are obtained by certain modifications of the theoretical tooth form. Teeth having an increase of pressure-angle and reduction of addenda to prevent undercutting on 12-tooth pinions would be subject to the same modifications which would put them in the empirical class, and any manufacturer of cutters would undoubtedly strive to improve his cutters regardless of whether they were strictly in accordance with theory.

The opinion is expressed that if such modifications are necessary, the methods should be known and clearly defined, so that makers of gears can use them and make their own cutters, if necessary. The advantages to the gear manufacturer of making his own cutters are not apparent to the writer, as the difficulties attending the making of form cutters would prove expensive in comparison with the convenience of using commercial stock cutters produced by reliable cutter manufacturers.

Attention has been called to the increasing number of gears cut by the hobbing process, and the difficulty of making such gears interchange with certain cut gears, thus demonstrating that the hobbing principle is the one to which all cutters should conform. This seems misleading, as the fact is not mentioned that this process has its limitations. It must not be overlooked that one great disadvantage arises from the difficulty experienced in producing accurate hobs.

The method of producing gear teeth by the shaping process has also been actively exploited, and the committee's attention has been called to the fact that it is an incidental feature of this process that the regular standard 14½-deg. cutters (on account of the side strain involved) are less durable than the usual form of revolving cutter, especially under rapid production requirements, and in tough material. The proposed 20-deg. pressure angle stub tooth materially increases the strength of the reciprocating gear-shaper cutter. The writer also calls attention to the fact that the stub-tooth system would greatly reduce the difficulties in producing the hobs for the hobbing process referred to above, and believes the committee should be very

conservative in its recommendations, particularly where they appear to favor some method or methods of producing gear teeth.

As regards the forms of teeth referred to in the paper as submitted by the other members of the committee, Mr. Fellows proposes to use an involute with 20-deg. pressure angle, and an addendum of $\frac{3}{4}$ of the modulus. Mr. Lewis proposes an involute with 22½-deg. pressure angle, and an addendum of $\frac{7}{8}$ of the modulus. Both of these systems are subject to criticism for general adoption, (*a*) because of increased angular back-lash, as compared with the present 14½-deg. standard for a like amount of wear; (*b*) decrease of addendum which is decidedly objectionable on the smaller pitches, as the liability of error in depth of tooth and center distance of shafts remains a constant for all pitches and sizes of gears, and the present height is none too great, being increased for these reasons for some purposes.

Further, it is claimed for the stub-tooth system that the arc of contact is equal to that of the 14½-deg. Brown and Sharpe standard, and that consequently the excess of tooth height in the standard system produces unnecessary friction and wear, which is eliminated in the stub-tooth system. The fact is not mentioned that in the Brown and Sharpe system the height of tooth permits of being eased off towards the point, with the result that it causes no friction if the integrity of the tooth form is maintained, but as wear cannot be entirely eliminated this easing of the points of the teeth allows the engaging teeth to come into action without shock, thus reducing noise and the dynamic action which tends to destroy the gears by the contacting of the teeth and is similar to hammer blows. Also, in practice the standard length of tooth will conjugate itself with its mating gear, with the result that more than one set of teeth take the load. This may produce extra friction, as claimed, but with properly lubricated gears this is a negligible quantity, as the unit stresses are divided over more than one set of teeth. The stub tooth has greater strength, but, for the reason cited above, does not prove as satisfactory for all-round service.

In this connection, the writer wishes to refer to the situation in motor gears used in street-car service. From personal observation he has seen stub-tooth gears where this dynamic action seemed to have broken down the structure of the steel to such an extent that it came off in splinters where the points of the teeth seemed to have bitten the material away. The best results the writer has seen in this class of work are where gears and pinions have been cut to the Brown and Sharpe system and carbonized and case-hardened, with the result that after a year's use there was only glazing of the contact surfaces.

As to the matter of testing, the committee are united on its desirability, but the writer does not believe that anything definite or conclusive can be obtained from testing a few pairs of gears. The tests should cover a large number of gears of more than one pitch and of several different ratios of teeth. These tests should be so exhaustive as to leave no opportunity for engineers to feel that anything has been assumed. This means great expense and much time, and the writer would recommend that the coöperation of all interested parties be secured, that a fund be raised for the purpose of employing competent engineers to conduct exhaustive tests with suitable apparatus, and that all available materials be used, so that the differences of opinion as to the efficiency of the various systems in use may be set at rest as far as possible. Also this should establish reliable data for proportions of gears of the various materials, now mainly a matter of judgment with the designing engineer, from which more gear failures result than from any fault of the system of teeth used.

To sum up the situation, the writer believes that where the limits of an interchangeable system are from a 12-tooth pinion to a rack, the present system is superior to any which are primarily based on the generating principle, in which the pressure angle and tooth parts are proportioned to facilitate the methods of producing and strengthening the cutting tools, rather than to improve the interchangeability or more quiet running of the gears, as that is a fact still to be demonstrated. The circular letter sent out by the committee brought out the information from one concern that it had experimented exhaustively with the hobbing system for a long time, with various tooth forms, but had gone back to the Brown and Sharpe standard, for which they had now worked out a most satisfactory method of making the hobs. This is another example of the working out of an empirical system, and any satisfactory system covering the range stipulated, which, as before stated, must be an empirical one, had best be left to responsible cutter manufacturers whose methods combine the theoretical with the practical. The present Brown and Sharpe system has proved itself eminently satisfactory for many years, and without most thorough investigation should not be given a place second to any other. Also the introduction of an alternative standard or standards is to be deprecated on the ground of causing confusion and economic waste, due to the increased stock of cutters required for use on all types of machines.

In conclusion, the writer wishes to refer to the point raised in some of the replies to the committee's letter, that the question of

standardizing gearing is of the same nature as screw-thread standardization, and can be treated in the same way. Without referring to the conclusions reached by the Committee on Screw Threads, the deliberations of which consumed several years, the writer fails to see wherein the problems set forth by the two subjects can be compared. The screw-thread situation was one to be settled by common consent of all concerned, while the problem of gearing is one that is worthy the life work of any engineer, and involves much of the higher mathematics of engineering, as well as a thorough knowledge of applied kinematics. The fact that such a comparison has been made by some writers on the subject, only serves to show an utter lack of appreciation of the magnitude of the problem set before the committee for its consideration and recommendation to the Society.

LUTHER D. BURLINGAME[1] said he appreciated all Mr. Vernon had said with regard to their policy at the Brown and Sharpe works, but he thought the point which had been raised was very well answered by the communication of Mr. Gabriel to which the members had just listened. Speaking for a manufacturer, at whose works for more than sixty years an extensive business in making gears and gear-cutters had been done, and which had had to deal with all phases of the gear question and meet the varying requirements of customers during those years, he could say they were not surprised that the different members of the committee of The American Society of Mechanical Engineers were not unanimous as to any plan which would bring about a change from the present standard. The thought seemed to be uppermost in the minds of those proposing a change that a standard should be adopted having a true involute for the entire length of the tooth, even if sacrifices in other directions must be made to accomplish that result. He believed the advantage, if any, of having the entire tooth a true involute was less than they would be led to believe by those advocating a change; indeed it was a matter yet to be demonstrated that the practical advantages of the form of tooth now in common use would not more than outweigh any theoretical advantages of a tooth wholly involute. The fact that the special requirements at the present time were for teeth varying both ways from the present standard would indicate that they now had a good average to meet ordinary working conditions. Their experience went to show that for quiet running for a possible variation in center distance and to avoid back-lash, a small pressure-angle and long teeth were of ad-

[1] Mem. Am. Soc. M. E.

vantage, while for cases in which strength was the prime consideration, even at the sacrifice of other advantages, the greater pressure angle and shorter teeth had their field of usefulness. Those varying needs were illustrated in automobile practice, where in some makes the cam-shaft gears were made with a small pressure angle and long teeth, while the driving gear was made with a larger pressure angle and shorter teeth, in each case for the reasons he had previously referred to. That strength in the latter case was secured at some sacrifice was indicated by the illustration used by Mr. Gabriel in his communication, where he spoke of the injurious effects of the hammer-blow action when "stub-tooth" gears were used in street-car service. The same destructive action had been noticed in stub-tooth gears used for automobile service. An engineer who had for many years made a specialty of gearing, and who was an expert on that subject, and who had in recent years been with one of the leading automobile manufacturers of America, told him that he had repeatedly found the same destructive action spoken of by Mr. Gabriel when stub-tooth gears were used in various makes of automobiles.

Mr. Lewis, in referring to the preliminary tests made by the students of the Massachusetts Institute of Technology, said they showed that the loss by friction was varied to a greater extent by the length of the addendum than by the angle of obliquity.[1] As he understood, the tests to which Mr. Lewis referred were made entirely with roller bearings, thus reducing the bearing friction to a minimum. That friction, however, was one-third greater for the 20-deg. pressure angle than for the 14½-deg. angle. With plain bearings, where the friction on the bearing would be much greater than with roller bearings, that factor favorable to the smaller pressure-angle might more than offset any advantage shown by the tests in favor of the greater pressure-angle as reducing friction. As plain bearings were more extensively used than roller bearings, the tests could not be considered complete without securing full data when using plain bearings. He agreed fully with Mr. Gabriel as to the need of exhaustive tests by competent engineers before any result could be accepted as authoritative.

He wished to take the present opportunity of endorsing what Mr. Gabriel had said relating to other phases of the subject. He did not believe that any modification of the present standard which would require more cutters in a set to ensure good running gears would meet with favor among manufacturers, as it would add di-

[1] Given verbally by Mr. Lewis when presenting his paper.—EDITOR

rectly to the cost of the equipment. All of the plans suggested in Mr. Lewis's discussion were such as would require extra cutters in the set. Neither did he believe that any plan would be generally approved which would increase the amount of back-lash with a given variation in centre distance or with a given amount of wear. Unless some very important advantages could be shown for some new system yet to be suggested, it would seem unwise to bring about the confusion which would result from a change not fully endorsed by the manufacturing public.

DANIEL ADAMSON[1] wrote that, as no doubt Mr. Steven's paper was intended to assist the proposed joint committee of The Institution and The American Society of Mechanical Engineers, he thought that one or two important processes for the production of gearing, which were not mentioned, should be referred to. There was no mention of the Sunderland method of generating spur gearing, the machines for which were at present being made by J. Parkinson and Sons, Canal Iron Works, Shipley. In this system the cutter took the form of a rack, and it was found that gears could be cut very much more rapidly than by rotary cutters, and the further advantage was that the cutters were much simpler and cheaper. Only one cutter was required for any number of teeth of a given pitch and the teeth were all correctly cut, as distinguished from the rotary-cutter system, wherein each cutter was only correct for the exact number of teeth for which it was designed.

He thought it seemed hardly fair to quote as a "difficulty" the fact that gears produced in hobbing machines by hobs cut to Brown and Sharpe standard would be unsuitable for running with those cut to other standard shapes. This was the fault of the difference in the so-called "standards" and was not the fault of the hobbing method, but was in fact the main argument for an early standardisation of all spur-teeth upon a definite system.

Coming to worm-gears, there was no mention of the Gibson system, which was described in the Proceedings of the North-East Coast Institution of Engineers and Shipbuilders in 1896-1897, Vol. 13. This system should certainly have some consideration, as he believed more worm-gears had been cut by this method and by the subsequently improved method introduced by Hy. Wallwork and Co., of Manchester, the licensees of the Gibson system, and known as the Wallwork-M'clean method, than by any other system.

[1] M. I. Mech. E., Messrs. Joseph Adamson and Co., Hyde, Eng.

In regard to the question of models of teeth there ought to be some consideration given to Lasche's paper in Zeitschrift des Vereines deutscher Ingenieure for 1899, Vol. 43, wherein was described a system recommended by its author for the use of the A. E. G. This system was based upon a 15-deg. angle of pressure with an addendum of 1½ module for the driver and ½ module for the driven wheel, and bore some resemblance to the Bilgram system referred to in Wilfred Lewis's paper. There were many advantages claimed for it, namely, a stronger shape for the teeth of the pinion, a shorter arc of approach, and (when a rotary cutter was used) a more effective cutting shape, the radial flanks of the pinion teeth being very much shortened.

No paper on tooth gearing could be considered complete without at least a reference to Michael Longridge, Member of Council, who gave, in his annual reports for 1887-1888 and 1891, examples of very short teeth for large driving wheels. It was principally upon the basis of those reports that Mr. Adamson's firm adopted a shortened form of tooth in 1897, full particulars of which would be found in Vol. 24, issue No. 39, p. 1079, of the American Machinist of 1901, and which he was pleased to notice had the same length of addendum as the "stub-tooth" given in Table 1 of Mr. Steven's paper, namely, 0.25 of the circular pitch.

In conclusion, he sincerely trusted that the proposed joint committee would be encouraged by the discussion on these papers to push forward the important question of standardization of gear teeth, and to put it upon such a basis that satisfactory gear teeth could be produced in the future from a definite formula, without the use of any empirical correction.

THOMAS HUMPAGE[1] said that he thought much credit was due to Brown and Sharpe for standardizing their system of toothed gearing, which was known and used throughout the world. It was, however, introduced before the generating machine was in use, and it must give place to something better now. In view of the great advances that had been made during the past ten years in high-speed machinery owing to the introduction of high-speed steel and the great demand for silent running gears, the writer thought that we were undoubtedly behind the times in producing correctly-formed teeth to run quietly at these high speeds with great pressure, and he welcomed

[1] M. I. Mech. E., Messrs. Humpage, Thompson and Hardy, Jacob St., Bristol, Eng.

any improvements that might be adopted to attain this end. The Brown and Sharpe system should be left alone, as it would always be retained by certain manufacturers because it was good enough for their class of work.

The rack being the basis of all generated involute gears, the teeth should have straight sides, leaving the usual fillets at their roots below the working depth; and no deviation from this form should be made. A 12-tooth pinion should be the minimum for general purposes, because it has proved best in the past. For quietness and long life at high speeds, it was most essential that there should be no undercutting, and that the involute should extend to the whole working depth of the tooth. To generate these teeth on a 12-tooth pinion, the cutter or hob must have teeth with sides inclined at an angle of 22 deg., as a less angle would shorten the length of the involute and cause undercutting. As regards the addendum and dedendum, he quite agreed with Mr. Lewis's suggestions. These teeth could be generated on either of the following generating machines—an automatic hobbing machine, a Bilgram, Reinecker or Sunderland spur-gear planer, also on a Fellows gear shaper, providing the teeth of the cutter were ground to a true involute form down to the working depth of the teeth. They could also be cut on any machine of the Brown and Sharpe type with disc cutters made the exact shape of the space between the teeth. All wheels cut on these machines would then be interchangeable with each other. To facilitate repairs, it would also be a great advantage if manufacturers would stamp the pressure angle on the rims of the gears they cut, for example—14½ deg. Brown and Sharpe, or 22 deg.

It was, however, most unlikely that all the branches of the engineering trade using gears would accept any one standard pressure angle only. Taking the automobile industry, for instance, a 20-tooth minimum pinion was adopted by leading makers, and for change-speed gears a pressure angle of about 18 deg. would be sufficient to extend the involute to the working depth of the teeth without undercutting. It would also enable all existing machines in motor-car works to cut interchangeable gears, providing their cutters were formed on an 18 deg. angle basis.

An 18-deg. angle involute tooth was much stronger than the 14½ deg. Brown and Sharpe standard tooth, which was the one generally adopted by the motor-car manufacturers, and owing to the involute being extended the wheels would run more quietly and last longer. The outward pressure would, however, be slightly increased above

the Brown and Sharpe standard, but it would be less than a 22-deg. angle. Again, in the printing machine and many other industries, the smallest pinions had more than twelve teeth, and a pressure angle of less than 22 deg. would be a great advantage owing to the fact that, when wear had taken place there was not so much back-lash and the machines registered more accurately.

The above suggestions appeared to the writer to be the first steps in the right direction leading up to the far more important and the much-desired object of producing perfectly silent running gears. In the writer's paper on Spur Gearing, read before the Institution at the Summer Meeting in Bristol of July 1908, he described a method of grinding the involute teeth of gear wheels. Since then he had continued his experiments, which he believed to be the best way of producing correct involute teeth and silent-running gears, and hoped shortly to make the results known.

R. M. NEILSON[1] wrote that, in view of the necessity of having maximum efficiency and a small angle of pressure in many cases where high powers were required to be transmitted, as, for example, in the propulsion of ships, it would appear to be advisable to have two standard types of teeth—one being of a nature to allow of the teeth being cut with a disc cutter for any number of teeth per wheel down to about 12 (or possibly less than 12), while the other would be designed for maximum efficiency and contact and a small angle of pressure, but would not be of a nature to allow of execution by a disc cutter except for wheels having a relatively large number of teeth. To attempt to make one standard serve in all cases would force the employment of non-standard teeth in many cases.

J. R. WILLIAMS[2] wrote that in his opinion the suggested increase in the angle of pressure, although good, both from the interchangeable point of view and increased strength of the teeth, would have a tendency to form shoulders on the working base of the teeth; this would, of course, increase the pressure on the bearings to a greater extent than the theoretical pressure, due purely to the increased angle, and would have to be allowed for when calculating the bearing surfaces for the shafts.

[1] M. I.Mech.E., 45 Hope St., Glasgow, Scotland.

[2] A. M. I.Mech.E., Tramway Power Station, Kelham Island, Sheffield, Eng.

CLOSURES

J. D. STEVEN wrote that, in reply to Mr. Vernon the conclusions and opinions stated bore some evidence of having been arrived at without due consideration of the knowledge we already had on the subject of gearing. With regard to silence in gears, the all-important points were accuracy in the machine, in the cutters, and in the methods of the operator who worked the machine. There was support for this statement in Mr. Gabriel's contribution, where he said that "nine-tenths of the trouble with noisy gears can be attributed to improper cutting." It was possible that the accuracy required was of a degree unnecessary for ordinary commercial work, and impossible for it on the score of expense. As it could be obtained, however, there was no reason why the question of an interchangeable gear system might not be considered apart from the silence problem, although Mr. Vernon appeared to object to this course.

Mr. Vernon stated that the experiments made by his firm in connection with gearing yielded little positive result. Whether this were the case or not, it seemed slender evidence on which to base the assumption that other investigations had proved equally futile in obtaining the information for which they were undertaken. He entirely disagreed with Mr. Vernon's view that what knowledge of gearing now existed was held by one American firm, and he did not think that this firm would for a single moment make any such claim on their own behalf. They had published books on the subject, their shape was so well known as to be spoken of as standard in many quarters, and original cutters could be produced from gages laid out to their figures, as was done in the author's own tool-room every day.

He was glad to see that Mr. Vernon and he were in agreement with regard to one point, and that was, they both recognised that there was no uniformity of opinion, and that everybody had more or less his own ideas on the subject of gearing. It was only by discussion on the subject that interest could be gradually aroused, and in the end possibly some uniform standard arrived at.

In reply to Mr. Gabriel he quite agreed in giving credit to Messrs. Brown and Sharpe for their work. Nothing was said in his communication, however, to alter the author's opinion as to the limitations of the Brown and Sharpe form. In his experience, which had not been as extended as he would wish, he had failed to observe the rapid wear which was stated to occur in gears of a greater pressure angle than $14\frac{1}{2}$ deg.

He felt that Mr. Burlingame's long familiarity with Messrs. Brown and Sharpe's methods was bound to make him doubtful about the advisability of change. He had personally no bias in favour of any particular shape, but he had certainly found that the 20-deg. stub form gave excellent results on the finer pitches, and saw no reason why it should not be suitable for larger gears. The loss by friction, which he mentioned on Mr. Lewis's authority, was hardly sufficient to prevent the adoption of a greater pressure angle, if it could be shown advisable in other ways. Neither did he (Mr. Steven) think it reasonable to object to a new shape because of possible variation in center distance, for to obtain the best results this dimension should be as correct as all others.

In reference to Mr. Adamson's remarks, he (Mr. Steven) saw what he believed was the first Sunderland machine made, and was much struck with the possibilities of the method. He did not, however, set out to describe all makes of gear-cutting machines in his paper, the object of which was to suggest an alteration in tooth shape. With this object in view he had only touched on a few typical methods of cutting. So long as the Brown and Sharpe shape was considered standard by a number of engineers, he was sure there was a very real difficulty in obtaining smooth running between teeth cut by Brown and Sharpe cutters and by other methods, and he used the word as a reason in favour of a new standard tooth shape. He regretted having had no experience of Lasche's system to which Mr. Adamson referred; but it seemed to him that with 15-deg. pressure angle only, there would still be undercut on the smaller numbers of teeth, and this would prevent them from being produced on a circular cutter machine. He was very pleased to note that generally Mr. Adamson agreed with the proportions for teeth suggested in the paper.

He noted that Mr. Humpage agreed with the author's suggestion for an increased pressure angle, but proposed to vary this for different kinds of gears. The author hardly saw it necessary to have so many angles. If it was necessary to have them, the change from the present practice would be expensive to general gear-cutters, owing to the number of hobs and cutters required. The same objection applied, in a lesser degree, to Mr. Neilson's suggestion.

Mr. Williams mentioned the extra wear referred to by previous speakers as occurring with greater pressure angles, and he (Mr. Stevens) hoped to investigate this point at an early date.

As most of the contributors to this discussion appeared to consider that the subject of tooth shapes was one which was now ripe for inves-

tigation, he hoped that the discussion would lead to wider interest and more definite conclusions later on.

WILFRED LEWIS wrote that since the paper had been written he had had an opportunity to make a short examination of the notes taken by Messrs. Green and Doble and from these he had deduced some values for the friction of gear teeth which might be given approximately as in Table 3.

TABLE 3 FRICTION IN TERMS OF PRESSURE

	In Teeth	In Journals	Total
20-deg., addendum ¾ module	0.008	0.002	0.01
22½-deg., addendum ⅞ module	0.01	0.002	0.012
14½-deg., Brown and Sharpe	0.0135	0.0015	0.015
Bilgram, 15-deg. special	0.0215	0.0025	0.024

These figures were subject to some variation for speed and pressure and also to correction by Professor Lanza in his review of the work done by his students, but he believed them to be substantially correct within 0.001 or 0.002.

They were quite remarkable for the small percentage of power lost in friction as well as for the apparent effect of pinion addendum upon the loss sustained.

The 20-deg. stub teeth with addendum about 0.24 pitch showed less than one per cent of friction on the teeth.

The 22½-deg. teeth with addendum about 0.28 pitch showed about 1 per cent of friction.

The Brown and Sharpe 14½-deg. teeth with addendum about 0.32 pitch showed about 1.3 per cent of friction and the Bilgrim special 15-deg. teeth showed over 2 per cent of friction.

In the latter case the addendum of the pinion was increased considerably beyond that of the Brown and Sharpe standard and the addendum of the wheel was, of course, correspondingly reduced.

The loss in effect from the long pinion addendum, however, preponderated over the advantage of a short addendum on the wheel with the resulting increase of loss in friction. But in no instance was the friction loss of sufficient magnitude to exercise a controlling influence upon the type of gear tooth to be recommended or adopted.

The loss in the teeth alone he believed to be much less than had

hitherto been commonly supposed, and the high efficiencies obtained with teeth of 20-deg. and 22½-deg. obliquity should go far toward removing the prejudice which had so long resisted a step in the right direction toward the adoption of a pressure angle and an addendum which would completely eliminate interference between a twelve-toothed pinion and a rack.

When this had been done, there would be no necessity for any modification of the true involute form, and we should have a clearly defined system of gearing to which any of the methods of gear cutting now in use could be easily adapted.

He said that the above conclusion appeared to be supported by Mr. Humpage in the results obtained by him in grinding the teeth to perfect involute forms after cutting them, and if this conclusion was sustained by further experiments which Mr. Humpage had in progress the results of which we should look forward to with interest, the contention that had been made for the necessity of some modification of the true involute form to produce quiet running gears, would certainly be seriously shaken. Such modified forms certainly could not be ground, and since the true involute form was the only one which could be treated in this rational way, the survival of the fittest would finally settle the question in the right way.

He had never doubted that silent running gears depended for their silence upon the degree of perfection realized in the forming and spacing of the teeth. He believed that good workmanship would produce perfect running gears whether they were cycloidal, involute or mongrel.

Brown and Sharpe had certainly been very successful with their empirical cutters simply because they had made them with great care, and the gears which they produced compared favorably with involutes or other types, because their standard of workmanship was of the highest class, but the same standard of workmanship when applied to involute gears would, he believed, produce better results.

He quite agreed with Mr. Gabriel in regard to the need of exhaustive tests made by competent engineers with ample funds at their disposal, but said that the committee was not yet in a position to carry this out and was simply doing its best to arouse the interest needed to bring out the needed funds.

He was well aware that the apparatus employed might be improved, and did not wish to have the results given above considered as anything more than tentative until satisfactory experiments had been made.

MPOSIUM ON RAILWAY ELECTRIFICATION

No. 1293*a*

ECTRIFICATION OF SUBURBAN RAILWAYS

By F. W. Carter,[1] Rugby, England

Non-Member

any of the railways of this country have, so far as their suburpassenger traffic is concerned, been affected very adversely in it years by the great and increasing competition of tramcars and or omnibuses. The companies concerned appear undecided at ent between giving up a great portion of this class of traffic perently and endeavoring to regain it by electrification of their subn lines. The latter expedient, although an expensive one, has erto invariably been found successful in regaining much of the traffic, and the problem confronting a company in regard to any on of its suburban lines is that of determining whether the expected from electrification will justify the expense to be incurred.

Modern electric railway apparatus leaves little to be desired in matter of freedom from breakdown, the delays from all causes rical and mechanical, for the month of December 1909 averaging it 33 sec. per day per train on the District Railway and only 2½ per day on the Underground Electric Railways tubes. The l cost for maintenance and repairs of rolling stock on these lines not exceed 0.6*d.* per car-mile.

There are 18 electric railways at present working in this coun- including seven tube lines; these comprise about 200 miles oute in all, and are for the most part worked by motor coaches, loying a multiple unit system of control. The coaches are geny of the saloon type.

[1] With British Thomson-Houston Co.

esented at the meeting of The American Society of Mechanical Eners with The Institution of Mechanical Engineers, London, Eng-, July 1910.

4 In typical suburban service the greater part of the energy input is used in accelerating the train, and the energy consumption per ton-mile depends principally on the nature of the schedule; in fact, this energy consumption is a good measure of the difficulty of a schedule, but an even better measure is the uniform acceleration that would cause the train to reach the mean running speed in a distance equal to the average distance between stations. This acceleration is greatest for the Liverpool Overhead Railway's schedule, a fact which explains the high energy consumption per ton-mile actually found in this service. A high initial rate of acceleration involves great mechanical strains on the bogies, and should not be employed unless the difficulty of the schedule renders it necessary. The equipment losses during acceleration are of the same order of magnitude in the continuous-current and the single-phase systems, in spite of the rheostat losses in the former system.

5 The performance of a given electric train under given conditions of suburban service can be very closely predetermined, for the factors liable to uncertainty have but small effect on the result. Schedule calculations, however, are inadequate by themselves to determine the question of the suitability of an equipment, as the limiting features are usually connected with the heating of the motors, which again depends on the energy loss in the motors. This loss is much greater in the single-phase system than in the continuous-current system.

6 There appears little prospect of general electrification of the railways of this country, as no advantage is apparent which would in any way justify the expense. It is only in the case of heavy suburban service that there is prospect of commercial advantage accruing from electrification, and whilst there may be other local opportunities for electrical working, there is at present no indication that the steam locomotive can be superseded with advantage for ordinary main-line work.

7 The shrinkage of suburban traffic has for several years past proved a source of lachrymose complaint at many of the general meetings of our railway companies. The extensive tramway systems that radiate from most of our large cities provide a convenient, cheap and comparatively rapid means of transport with which the railways are ill-adapted to compete. Where a tramway runs directly parallel to a railway, it may be expected to secure the greater portion of the purely short-distance traffic, and it would seem that the distances over which its competition is effective are greater than might at first be supposed. At the general meeting of the London

& North Western Railway, held on February 19, 1909, the chairman in discussing this point said that, "he would be unwilling to say what the distance was (it might be 10 or 12 miles), but after such a distance the railway was the more punctual and the more certain way for a man to get to his destination. Within the 10 or 12 miles the tramway competition was very severe, but beyond that distance the railways were not so much touched by the tramways." The advent of the motor omnibus has also affected suburban railway traffics adversely, particularly in the neighborhood of London, the flexibility of its route, its speed and general convenience giving it a great advantage in ministering to the needs of comparatively short-distance passengers.

8 With the main routes of street traffic worked by tramcars and auxiliary routes by motor omnibuses, the railways as at present operated are at a great disadvantage, and bid fair to lose most of their suburban passenger traffic. The second report of the London Traffic Branch of the Board of Trade[1] gives the loss of passengers by five railways as upwards of 12,000,000 in 1908 as compared with 1907, and of 47,000,000 in 1908 as compared with 1902, both figures being exclusive of season-ticket holders, and taking no account of the increase in the number of long-distance passengers indicated by the receipts.

9 The railway companies affected appear for the most part undecided between allowing their short-distance traffic to go, employing their energies in fostering the longer-distance traffic, and endeavoring to reduce the effective range of tramway competition by electrification of their suburban lines. The latter alternative, wherever it has been tried, has invariably succeeded in recovering a portion of the lost traffic, besides creating a more desirable traffic for longer distances by the improvement of facilities. Whilst it is by no means certain that local electrification would prove the best commercial policy in the case of all railways handling suburban traffic, it is the author's opinion that there is considerable scope for well-considered electrification schemes in this country.

10 Where a suburban railway is regularly used to near the limit of its capacity and there is still possibility of increased traffic, there is every reason to expect a commercial advantage from electrification. Both here and abroad the improved service has always been the means of largely increasing the traffic, whilst the capital cost is

[1]Cd. 4988, pp. 38 and 131.

further justified by the greater use that can be made of existing lines and terminals under electrical operation. The cost of electrification should in fact be set against the cost of widening and improving the railway to accommodate the traffic in view.

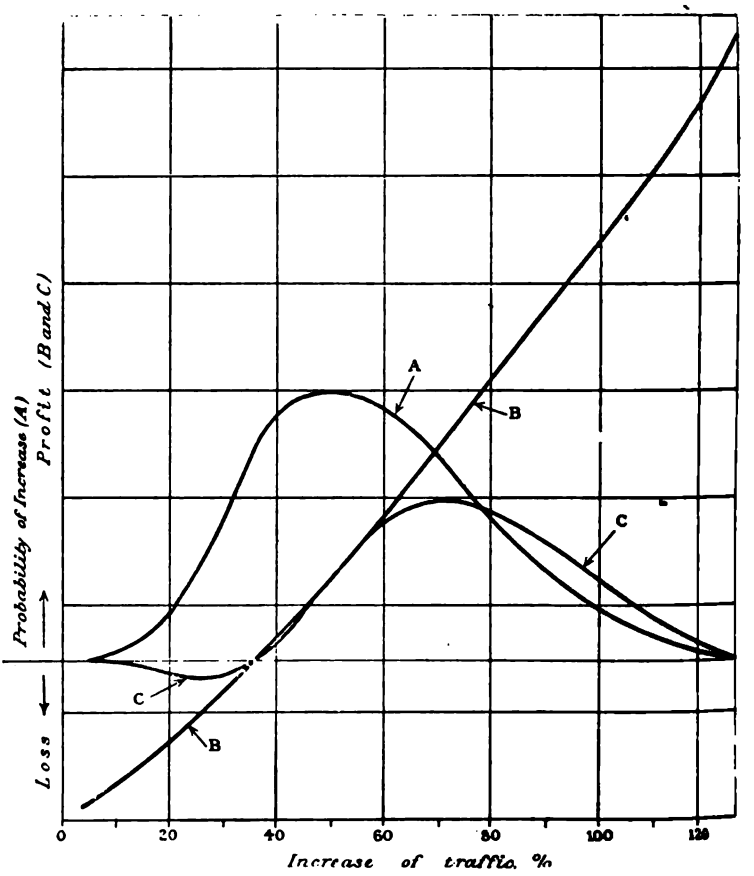


FIG. 1 ESTIMATION OF PROBABLE PROFIT

11 In the more usual case, however, the management of a railway are compelled to estimate the chances of success from far less certain data. Consider, for instance, the line from Birmingham (New Street) to Sutton Coldfield and Four Oaks. It passes through a populous and growing residential district, feeding also one of the most beautiful pleasure resorts of Birmingham people. The present trains, of which there are about 30 per day in each direction, make a schedule speed, including stops a little over a mile apart, of approximately

18 mi. per hr., the grades being rather severe. As the whole distance n question is little more than eight miles, it is small wonder that the ramway, which now parallels the line for a considerable distance and offers a frequent service at low fares, takes the greater part of the raffic so far as it extends. Although the population served has argely increased in recent years, the passenger traffic on the railway appears to have decreased considerably since the opening of the tramway, and will doubtless decrease still further as the tramway is further extended. If this section of the railway were electrified, the schedule speed might be increased by 30 per cent or 50 per cent and trains run every 15 min. or so throughout the day, say two-coach trains during hours of light traffic and six-coach trains during the busy hours. The capital cost of electrification and the expense of such electrical working could be very closely estimated. The real difficulty which confronts the management is in estimating the increase in receipts which would accrue from the improved facilities. This is an economic problem to which no certain answer is possible. So many considerations enter into the matter that experience in one locality s no sure guide in making an estimate for another.

12 The appropriate method of treatment for any such problem in stimation is provided by the theory of probability. If from the xperience of other electrified lines, and from knowledge of the particular district, such a curve as A (Fig. 1), can be improvised (the bscissae of which represent the increase of passenger traffic resulting rom a certain improvement in facilities, whilst the ordinates are proportional to the probability of such increase), the probable value f the advantage of providing the improved facilities can be deduced. Assuming the operating and capital expenses known, the net profit vith any particular traffic can be deduced. Let the increase of profit above the old method of operation be represented by curve B, and deduce curve C, whose ordinate is the product of the ordinates of curves A and B. Then the area of curve C, as compared with that of the probability curve A, gives the probable value of he advantage of providing the improved facilities. While the probbility curve may be subject to considerable uncertainty, the result f such calculation as indicated above, if properly interpreted, is kely to be of much greater value than a figure derived from a imple estimate of the increase of traffic.

13 It has generally been found hitherto that the increase in traffic ue to electrification has exceeded the estimates formed of it. Thus t the February 1905 meeting of the Lancashire & Yorkshire Rail-

way Company, the chairman stated, concerning the electrified Liverpool-Southport line, that "the increase in the traffic had exceeded their most sanguine expectations." At the February 1906 meeting of the North Eastern Railway Company, the deputy chairman, referring to the Tynemouth electrification, said that "in the last half of 1903, with steam traction, they had 2,844,000 bookings, and in the last half of 1905, with electric traction, they had 3,548,000, an increase of, in round figures, 25 per cent. In 1903 the gross amount of money earned with steam traction was £129,000, and in 1905 with electric traction the gross amount of money earned was £151,000, and they had run in 1905 twice as many trains as in 1903. In 1903, to earn the £129,000, the running expenses amounted to £42,761, while to earn the £151,000 it cost £47,799, which was only £5000 more to do twice the work in 1905 that they did in 1903. He would give the figures in another way, as many persons were interested in train-mileage cost. In the electric traction on the 31 miles of suburban railway in the Newcastle district they had practically doubled the train mileage and doubled the accommodation of the public, and the running cost per train-mile, allowing for depreciation of stock, etc., has been with electric traction about 9*d*. per train-mile as compared with 1*s*. 5½*d*. per train-mile under steam conditions. They had run smaller trains but there were more of them. They were thus able to serve the public better and at the same time to make a better profit for themselves." At the February 1907 meeting of the North Eastern Railway Company, the deputy chairman explained that in the last half of 1906 they had carried 4,195,339 passengers on the electrified lines as against 3,548,206 in the corresponding half of 1905, a further increase of 18 per cent, making a total increase of 47½ per cent as compared with the last half-year that steam operation was exclusively employed. At the last February meeting of the London, Brighton & South Coast Railway Company, the chairman announced that the increase in passengers on the elevated electric line between Victoria and London Bridge for the two months, December 1909 and January 1910, during which the line had been open, was, as compared with the corresponding period of 1908–1909, 440,536, or 63 per cent.

14 It has been stated above that the capital outlay and operating expenses can be closely approximated in any particular case. The amount will depend largely on the difficulty of the proposed schedule. It is in the power of electricity to improve very greatly on the performance of steam trains; but the greater the improvement, the

higher the capital and operating costs and the greater the attractiveness of the line. It is a matter of nice estimation and computation to determine what improvement of service will result in the greatest commercial advantage to the railway. The Tynemouth lines and the Liverpool-Southport line do not differ greatly in the distance between stops. The schedule speed is however considerably higher on the Liverpool-Southport line, and the effect of this on operating expenses is to some extent revealed in the above extract from the statement of the North Eastern chairman as compared with that of the Lancashire & Yorkshire chairman at the February 1906 meeting: "they found after a full year's experience that the cost of electric working, as they had expected, was, when proper allowances were made for the depreciation of the more costly plant, slightly higher per train-mile run" (than that of a steam working). Other features doubtless affect the comparison,[1] but the greater portion of the difference in running cost can probably be ascribed to the difference in the schedule speeds.

15 The electrification of a steam railway can of course be considered commercially expedient only when the estimated net profit under electrical operation exceeds that under steam operation by more than the interest on the extra capital involved. It is chiefly the burden of capitalization which limits electrification to lines of heavy traffic. The extent of the burden is in practice very variable. The total capital involved in the Tynemouth electrification to date is approximately £244,000, and the annual electrical train-mileage, 1,215,000[2]; taking the interest at 4 per cent, which appears to be about the average value of railway investments here, the capital burden is seen to be about 1.93*d.* per train-mile. Again, the capital involved in the electrification of the South London elevated line has been given as approximately a quarter of a million sterling[3] and the yearly train-mileage is at present some 375,000, to be eventually increased to approximately 585,000 miles.[4] The burden of the capital is therefore about 6.4*d.* per train-mile at present decreasing to 4.1*d.* if the improved service can be realized without adding to the

[1] From Board of Trade Railway Returns, 1908, it would seem that the coaches per train average 3.4 for the L. & Y. Railway, and 3.1 for the N. E. Railway. See also President's Address, Proc. I. Mech. E., 1909, Pt. 2, p. 432.

[2] Board of Trade Railway Returns, 1908.

[3] Electrical Review, vol. 56, p. 953.

[4] Light Railway and Tramway Journal, vol. 22, p. 17.

capital expense.[1] The capital burden in the case of the Mersey Railway has been given as 4.3*d.* per train-mile, and in the case of the Lancashire & Yorkshire electrified lines as about 2*d.* per train-mile.[2] These two cases of course include generating station, which is absent in the first two.

16 An indispensable requirement to the success of any system for working suburban traffic is immunity from all forms of breakdown competent to delay the service. In this respect modern electric railway apparatus, the design and construction of which has been developed by arduous experience, if chosen with reference to the nature of the service and maintained with care, leaves little to be

TABLE 1 TRAIN DELAYS, DECEMBER 1909

	District	Tube*
Total number of train-miles	401,295	490,900
Total number of delays (all causes)	303	44
Total time lost by delays, min	1186	167
Train-miles per delay	1324.4	11,361
Train-miles per min. lost	338	4672
Total number of delays due to electrical troubles on the trains	54	21
Time lost due to electrical troubles on the trains, min	135½	75
Train-miles per electrical delay	7431	23,376
Train-miles per min. delay on account of electrical troubles	2961	6535
Average mileage per train per day	185	194.5
Average delay per train per day due to electrical troubles on the trains, min.	0.068	0.03
Average delay per train per day due to all causes, min	0.548	0.08

*Baker Street & Waterloo Railway; Great Northern, Piccadilly & Brompton Railway; Charing Cross, Euston & Hampstead Railway.

desired. Even when first installed the troubles are usually of a minor character, and the consequent delays unimportant, whilst ordinary operation is exceedingly reliable so far as the electrical plant is concerned. The author is indebted to Mr. James R. Chapman, late Chief Engineer of the Underground Electric Railways Company of London for the following figures, giving particulars of all delays on lines under the company's control for the month of December 1909 (Table 1). The much greater loss of time on the Metropolitan District Railway, as compared with the tube lines, is almost entirely due to the fact that district trains operate to a considerable extent

[1]This would involve running each of the present eight trains an average of 73,000 miles per annum.

[2]Proc. Inst. C. E. vol. 179, pp. 42 and 119.

er foreign lines, worked for the most part in the interests of steam ains.

17 The comparative immunity from breakdown is duly reflected the low maintenance costs of the train equipments. Mr. Chapan dealt with this subject at a valedictory dinner given in his honor 1 February 7, 1910, on the occasion of his retirement from the posion of chief engineer to the Underground Company. He said at they (the Underground Railways Company) "owned over 800 otors, and that every one was the same throughout, no matter hether it was working on the district or a tube, under a car or on a comotive, all were interchangeable; and today, several years after the riginal purchase, they were negotiating for some more of the same otors to meet the increased traffic requirements of the District ailway. On no one of their properties did the cost of rolling-stock aintenance and repairs exceed 0.6*d*. per car-mile. The ten District ailway electric locomotives, now five years old, made 1300 mi. per ay at a cost of ½*d*. per mi. for all maintenance and repairs. Two of hem coupled handled a London & North Western Railway nine-oach train to Mansion House far better than a steam locomotive ad ever done. The maintenance cost was 1*d*. per train-mile. The Vorth Western costs for maintaining a steam locomotive were 4*d*. er mi.; the average cost for all English railways was 3½*d*. per mi. ive years after this system had been designed, the Pennsylvania ailway had experimented for two years at a cost of $200,000 to etermine the electric system to be adopted for bringing their trains rough the Hudson River Tunnel into their magnificent New York rminal, and had decided in favor of the same system as they (the nderground Railways Company) had today."

18 The railways in this country operated wholly or in part elec-ically are 18 in number, working over a total of approximately 0 miles of route and 410 miles of track. The trains are worked y 87 locomotives and 821 motor coaches. The aggregate nominal ower of the driving motors is approximately 360,000 h.p., of which 4,000 h.p. is provided by one type of motor alone, namely, that used clusively by the railways operated by or in conjunction with the nderground Electric Railways Company, London,[1] and partly y the Metropolitan Railway.

19 Of the 18 electric lines 13 are in the London area (including

[1]The Metropolitan District; Baker Street & Waterloo; Charing Cross, uston & Hampstead; Great Northern, Piccadilly & Brompton; London, ilbury & Southend; and Whitechapel and Bow Railways.

seven tube lines), three in the neighborhood of Liverpool, one at and near Newcastle and one between Heysham, Morecambe and Lancaster. As full details of all the lines have been published (Appendix No. 1), there is no necessity to give more than a brief comparative summary here.

20 The oldest of the London lines is the City & South London Railway, which was not only the first tube railway but one of the first electric railways to be constructed, having been opened for traffic in 1890. It extends for 8 miles, from Clapham Common to Euston, and is carried in a 10 ft. 6 in. tube. It is unique among electric railways in transmitting high potential continuous current (2000 volts) and distributing to the trains by the three-wire system, the up and down track conductors being of opposite polarity, whilst the track rails form the middle conductor. The traffic is still worked exclusively by electric locomotives.

21 The Waterloo and City line of the London & South Western Railway is also comparatively old as electric railways go. It is 1½ miles long, and is carried in a 12-ft. tube. The trains are worked by motor coaches, mounting for the most part gearless motors, directly controlled. The track rails are used as return conductors.

22 The Central London Railway was the first to employ polyphase transmission of power and conversion to continuous current at sub-stations. The line is 6½ miles long, and is carried in an 11-ft. 8-in. tube. The traffic was originally worked by locomotives, but is now handled entirely by multiple-unit trains using the electro-magnetic system of control, this railway having been the first to employ the multiple-unit system of operation. Power is supplied to the trains by a third rail, and the track rails are used as return conductors.

23 The Great Northern & City Railway is the only tube sufficiently large to accommodate main line rolling stock, the minimum internal diameter being 16 ft. It is 3½ miles long, and is supplied with power from a central power station, which feeds directly to positive and negative conductor rails. The trains are of the multiple-unit type, using the electro-magnetic system of control.

24 The Underground Electric Railways Company of London operate three tube lines, namely, the Baker Street & Waterloo Railway (4¼ miles), the Great Northern, Piccadilly & Brompton Railway (9 miles), and the Charing Cross, Euston & Hampstead Railway (8 miles). These are all run in tubes of 11 ft. 8 in. minimum diameter. Power, which is generated at the company's great power-station at Lots Road, Chelsea, is supplied to the railways through 12 sub-

stations, being distributed to the trains by positive and negative conductor rails. The traffic is worked exclusively by multiple-unit trains using the electro-magnetic system of control.

25 The Metropolitan District Railway comprises 25 miles of route, but, including running powers, operates over 56 miles in all. Of this, 41 miles is supplied with power from Lots Road power station, through 15 sub-stations, it being distributed to the trains by positive and negative conductor rails. The District trains are of the multiple-unit type, using the electro-magnetic system of control. A number of foreign trains are brought to the company's lines at Addison Road Station, whence they are hauled by electric locomotives. The Whitechapel & Bow Railway and the electrified portions of the London, Tilbury & Southend and the London & South Western Railways are worked in conjunction with the District, using the same or similar rolling-stock and their route mileage is included in the 41 miles given above.

26 The Metropolitan Railway has some 26 miles of its lines electrified. It employs the same system of operation and the same location of conductor rails as the Metropolitan District Railway; the Inner Circle being, in fact, jointly worked by the two companies. The Metropolitan Company generate power at their own power-station at Neasden, which feeds their lines through nine sub-stations. The trains are, for the most part, of the multiple-unit type, both the electro-magnetic and the electro-pneumatic systems of control being used. A number of trains are made up of the old steam stock and hauled by electric locomotives, which also handle the goods traffic over the electrified lines.

27 The Hammersmith & City Railway is a joint Metropolitan & Great Western line. Except on the Metropolitan section between Aldgate and Pared Street Junction, the power is supplied by the Great Western Company's power station at Park Royal. The trains are of the multiple-unit type, the electro-magnetic system of control being used.

28 The electrified section of the London, Brighton & South Coast Railway extends for 8½ miles from Victoria to London Bridge Stations, via Bruxton. It has the distinction of being the first of the London railways to adopt the single-phase system of operation. It is supplied with power at 6600 volts, 25 cycles single-phase, by the London Electric Supply Corporation, the feeding cables being run to a central distributing cabin at Denmark Hill through a metering cabin near Queen's Road Station. Thence the power is conveyed

to a number of switch cabins which feed the overhead track conductors. The outer of the concentric distributing cable is bonded to each length of track rail and forms the return conductor. The trains are of the multiple-unit type, employing the electro-magnetic system of control.

29 The Liverpool Overhead Railway is one of the oldest of electric railways, having been opened for traffic in 1893. It is 7 miles long, and carried on an elevated structure alongside the docks. It is a third-rail line, fed from a power station near its centre. The service was reorganized and greatly accelerated in 1902. The trains are worked by means of motor-coaches, the motor control being directly operated by the driver.

30 The Mersey Railway has $4\frac{3}{4}$ miles of route, connecting Liverpool with Birkenhead by means of a sub-aqueous tunnel. It was converted from steam to electricity in 1903, largely on account of the difficulty in maintaining efficient ventilation in the tunnel. Power is supplied from a central power station directly to the conductor rails. The trains are of the multiple-unit type, the electro-pneumatic system of control being used.

31 The Lancashire & Yorkshire Railway have some 28 miles of route electrified in the neighborhood of Liverpool. Power is generated at Formby power station, and transmitted to four rotary sub-stations, whence it is distributed to the third rail, and also to a number of battery sub-stations. The return conductor is an uninsulated fourth rail, bonded to the track rails. The trains are worked by motor coaches, of which the motors are for the most part directly controlled by the driver, although a few multiple-unit trains have recently been introduced, using an electro-magnetic system of control.

32 The North Eastern Railway have about 30 miles of electrified route in their Tynemouth lines. Power is bought from the Newcastle Electric Supply Company and transmitted three-phase to the five sub-stations which feed the conductor rails. The track is used as return conductor. The trains are of the multiple-unit type and employ the electro-magnetic system of control. Some of the later coaches are equipped with commutating-pole motors, the North Eastern being the first railway in the country to use this type. A quantity of fish and parcel traffic is handled by special motor-vans, whilst two electric locomotives handle goods trains, particularly on the Quayside line.

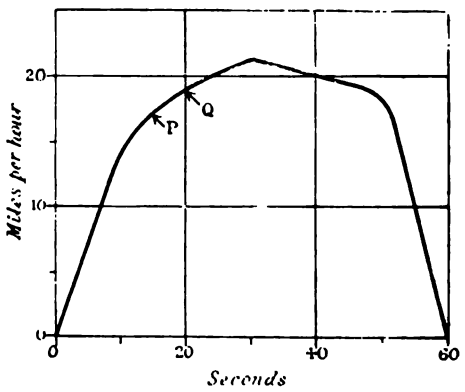
33 The Midland Company's electrified line at Heysham is an interurban one of an experimental nature, it being the first single-

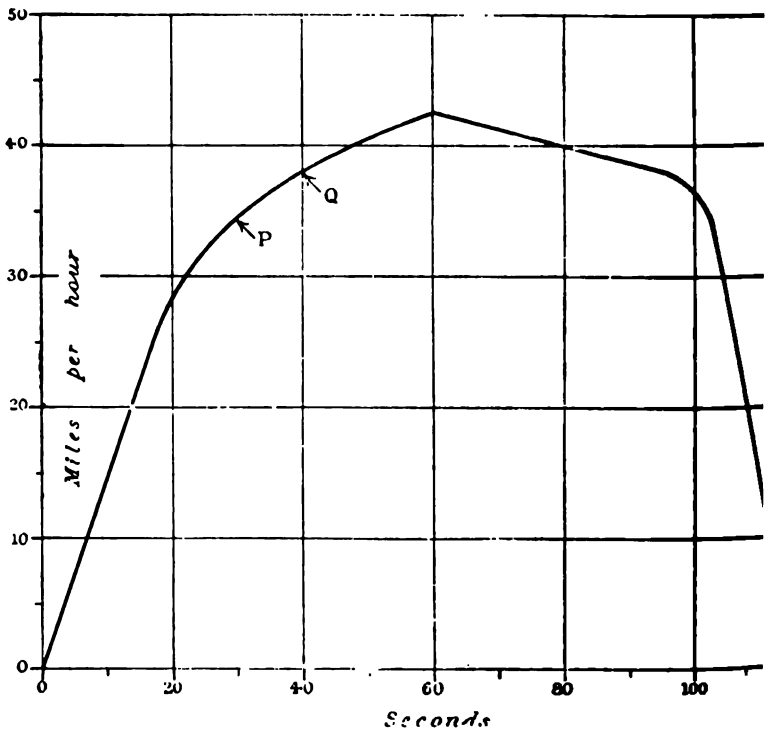
ıase railway opened for traffic in this country. It comprises some ght miles of route, and as there are only three stations, the average ngth of the run is about four miles, so that the service has little in ɔmmon with that on a suburban railway, lacking the features which ɔ to make the latter class of service particularly difficult to operate. 'he line is fed from the harbor power station at Heysham. The trains re of the multiple-unit type, both the electro-magnetic and the lectro-pneumatic systems of control being used.

34 It will be seen that by far the greater portion of the electrically perated traffic is worked by motor coaches rather than separate locomotives. This method of operation is peculiarly adapted for working suburban railways and will no doubt remain the standard. The hief advantage of locomotive operation is that the greater portion ɔf the electrical apparatus is immediately under the eye of the lriver. If the apparatus were less immune from breakdown this would be worth making considerable sacrifice to attain, but practically the advantage is small, as balanced against the advantages of notor-coach operation. The multiple-unit system of control in which :he motors on any bogie and the corresponding motor controllers :orm a unit (all such units on a train being operated from the driver's :ab) is practically universal in the latest equipments, as well for locomotives as for motor coaches. Most of the multiple-unit trains used on surface lines carry the motor-controlling apparatus suspended on the underframe of the motor coach. In the case of the tube lines, however, it is invariably located inside the motor coach, in order to be accessible in case of emergency. In the smaller tubes the control compartment is placed over the motor bogie on a raised platform.

35 Most of the passenger coaches are of the saloon type; there is, of course, nothing in the nature of electrical working to render this type of coach indispensable, although the shortness of the station stops and the high rates of acceleration usual in electrical service, render it preferable from the operating point of view. Some of the most popular of the Metropolitan Railway trains, however, are of the compartment type, being bogie trains, dating from the time of steam operation, converted for electrical working.[1] These trains consist of seven coaches, of which the end ones are motor coaches; :hey weigh, unloaded, some 172 tons and seat 400 passengers (120 irst class and 280 third class). The controlling apparatus is located

[1]Tramway and Railway World, vol. 20, p. 325.





FIGS. 2 AND 3 SPEED-TIME CURVES CORRESPONDING TO TWO SCHEDUL

hat was formerly the guard's compartment, of which the fore-end
as the driver's cab.

6 The London, Brighton & South Coast Railway have sought
ombine some of the advantages of both types of coach in the new
ng-stock for their South London Elevated Electric line. The
:hes are of the corridor type, being divided into compartments,
having side doors, but having a corridor running the length of
coach for distributing the passengers. The trains consist of three
ches, of which the two end ones are motor coaches; they weigh
oaded some 138 tons and seat 188 passengers.

7 Although most of the railways in this country employ the
uum brake, the electric railways, with the exception of the Lanca-
'e & Yorkshire and the Midland, have adopted the Westinghouse
e of brake. The chief reason for this is that compressed air can
stored to take off the brakes at a moment's notice. If the vacuum
ke be employed it is necessary to use a rather large exhauster, in
er to fulfil the function of the large ejector on a steam locomotive
producing a vacuum rapidly. The space and material are, there-
:, not used to advantage in this system as compared with a press-
system. The locomotives used on the London Underground
ilways, having to work trains of all kinds, are fitted to use either
tem.

8 In suburban service the greater part of the energy expended is
d in giving speed to the train and is ultimately dissipated in the
kes. Other things being equal, therefore, the more frequent the
)s the greater is the energy required per mile, and the more diffi-
t the service. The energy consumption per ton-mile, unless ab-
mal, is, in fact, a very good measure of the difficulty of a service.
his were more generally realized the world might be spared some
he absurd comparisons of energy consumption between different
tems, in which credit is claimed for obtaining a low energy
sumption, which is really due to comparatively easy service. As
author has pointed out elsewhere,[1] the figures derived from test
2 watt-hr. per ton-mile for the energy-consumption of the Central
ndon Railway trains and 137 watt-hr. per ton-mile for the Liver-
l Overhead Railway trains, are strictly comparable and indicate
more than totally different services on totally different railways.

9 If it be granted that the natural and normal energy consump-
n per ton-mile is a reasonable measure of the difficulty of a schedule,

[1] Proc. Rugby Engineering Society, vol. 6, p. 39; Electrical Engineer, vol.
p. 303.

an even more reasonable measure is to be found in a certain acceleration immediately expressible in terms of the particulars of the service, namely, the acceleration that would cause the train to reach a speed equal to the mean running-speed in a distance equal to that between stops. This is merely a dynamical result, and in order to show it, let Figs. 2 and 3 represent speed-time curves corresponding to two schedules, the curves being such that that of Fig. 3 is simply that of Fig. 2 magnified twice in every direction. The distance represented in Fig. 3 is then four times that in Fig. 2. At corresponding points P on the two curves, the acceleration, and therefore the tractive effort per ton necessary to produce it, will be the same. The power per ton required at P to produce the acceleration, being proportional to the tractive effort and speed, is twice as great in Fig. 3 as in Fig. 2. The energy per ton required to accelerate between corresponding points P and Q, being proportional to the power and to the interval of time, will be four times as great in Fig. 3 as in Fig. 2. But the distance is also four times as great, and thus the energy per ton-mile used in accelerating (probably some two-thirds of the whole) is the same for the two services. If the mean train-resistance per ton were the same for the two curves, the energy per ton-mile required to overcome the resistance would also be the same, and we might thus assert that the total energy output per ton-mile would be the same in the two cases. As it is, there is a small error affecting a comparatively small portion of the energy, which will have to be neglected. This is in general of little consequence in cases in which it would be expedient to employ the result, that is, in suburban service, where a ratio of four to one in distance with similar speed curves is, of course, a very exaggerated case. It will be seen that the acceleration referred to above, which will be called the specific acceleration of the schedule, is the same for the two curves, being the square of the mean running speed divided by twice the distance. It will also be seen that the method is perfectly general: so long as the speed-time curves for two services are similar the specific acceleration will be the same, and the energy output of the equipments practically the same. It follows that of two services, that having the higher specific acceleration may be expected to show the higher energy consumption per ton-mile. Also that if two services have the same specific acceleration but differ in energy consumption the higher can be reduced, in so far as it is not due to lower equipment efficiency, by running so as to assimilate its speed-time curve to that of the lower.

40 The specific acceleration of a schedule is a better index of the

lty of the schedule than the energy consumption, inasmuch as ıdependent of the equipment efficiency and of the particular ɛr of running the schedule, in effect reducing equivalent ser- to the same mode of operation. This, of course, presupposes he line is not specially graded to reduce the difficulty of opera- The Central London Railway, for instance, was so laid out ach station is at the top of a grade; thus energy that would vise be dissipated by the brake shoes is stored and used for rating, making the line easier to work and the energy consump- ıwer than would be indicated by consideration of specific accel- n alone.

TABLE 2 CHARACTERISTIC SCHEDULES

Line	Average distance between stops, ft.	Schedule speed, mi. per hr.	Time of stop, sec.	Average speed excluding stops, mi. per hr.	Specific acceleration, mi. per hr. per sec.
ıl Overhead	2145	19.5	11	22.9	0.179
ıl-Southport	6535	30	15	33.4	0.125
ound, Inner Circle	2555	15.7	20	19.2	0.106
ıreet and Harrow	5000	23	20	26.6	0.104
ondon Elevated	4540	21.5	20	25	0.101
smith and City	2830	16	20	19.2	0.096
London	2540	14.7	20	17.7	0.090
astern, Tynemouth	6000	20.5	30	24.1	0.071
, Heysham-Morecambe	23500	26.7	120*	33.4	0.035

ıamed.

The above is an application of a method which the author has fully elaborated elsewhere.[1] Table 2 gives some characteristic ıles arranged in order of difficulty as indicated by the specific ration.

A difficult service (in the sense of a service in which the specific ration is high) is one in which it is advisable, in the interests energy consumption, to employ high rates of acceleration and ation; in an easy service this is of smaller consequence and worth securing at the cost of heavy mechanical strains on the , etc., with the great draft of power incident to the use of a ate of acceleration. The account of the tests on the Liverpool ead trains indicated a maximum rate of acceleration of 4.2 sec.[2] (2.9 mi. per hr. per sec.), and this is perhaps as high as it

ns. A. I. E. E., vol. 20, p. 991; Journal Proc. Inst. E. E., vol. 36, p. 240.
Engineer, vol. 93, p. 284.

is advisable to employ in service. The author has a record of a run actually made with a coach carrying a motor on each axle, in which an average rate of acceleration of 4.2 mi. per hr. per sec. was maintained until a speed of 21 mi. per. hr. was reached (Fig. 4). The test was made with a view of showing the possibility of electrical equipments in this connection, and the acceleration was certainly faster than would be considererd comfortable to passengers.

43 During the period of acceleration by controller notching considerable energy loss is inevitable in the equipment. In the continuous-current system the average equipment efficiency during notching is usually only about 57 per cent, the remaining 43 per cent

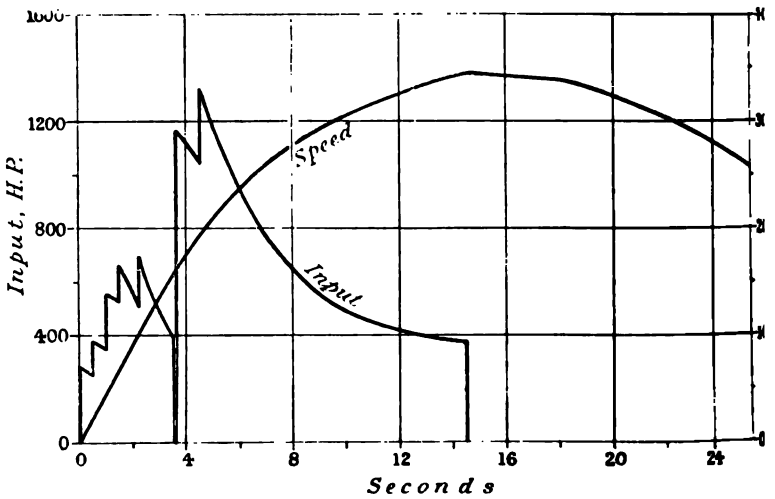


FIG. 4 TRAIN CHARACTERISTICS

being lost in the motors, rheostats, etc. It has been hastily assumed by some that the avoidance of rheostat losses in the single-phase system would result in much lower losses and higher mean efficiency during notching. That this is an unwarranted conclusion is shown by the authors of a recent paper on the Heysham electrification who, although by no means blind to the merits of the single-phase system, found as the result both of test and calculation, that the mean efficiency of the equipment during notching was only 56 per cent the cases considered. The efficiency after notching is of course of

[1]Proc. Inst. C. E., vol. 179, pp. 188, 189.

erably higher for continuous-current than for single-phase equip-ents.

44 The claim that the performance of a suburban electric train n be very closely predetermined may seem an extravagant one, until is considered how very few are the conditions on which it depends. ıe relation between the tractive effort and speed of a given motor perfectly definite, but subject to small known variation with tem-rature, at any given voltage, as is the current taken, whilst different otors of the same type agree closely in their characteristics. Assum-g the train known as to weight, size, etc., the resisting forces due grades, inertia and train resistance are known. It, therefore, re-ıires a dynamical calculation of no great difficulty to determine the fect of the motors on the train for any particula rroute or schedule. he quantities most likely to be subject to some uncertainty before-ınd are the voltage at the train and the train resistance. In sub-·ban work, however, a small error in these has but little effect either ı the schedule speed or energy consumption. Perhaps an idea of ıe accuracy with which the running can be predetermined will be ;st conveyed by disclosing that the author's practice, in making a ıarantee of energy consumption, is to compute it as closely as pos-ble under the expected conditions of test and add 5 per cent to cover ıd driving and other unforeseen contingencies. Such a guarantee ould, of course, be of little use unless accurate instruments were ·ailable for making tests. Train-testing instruments should be ›ecially designed for the work, so as to secure exceptionally large ›rque and heavy damping. The delicacy of ordinary stationary ;truments renders them useless for train-testing where they are ıbject to great vibration in all directions.

45 These schedule calculations are easy and commonplace but ıite inadequate by themselves to determine whether an equipment suitable for a given service. More important in this connection e the calculations involving the magnitude and distribution of the ;ses in the motors, with the facilities for transferring and dissi-ıting the heat generated. Such calculations are, however, almost cessarily confined to the designers of equipments, as the data on ıich they are based are not generally available. In order to give ·ough idea of the quantities involved, it may be stated that the ulti-ate temperature rise of the hottest accessible part of an ordinary ilway motor, totally enclosed and without forced ventilation, as easured by centigrade thermometer after continuous service, is ven approximately by

$$T = 7Ww^{-\frac{1}{3}}$$

where W is the mean motor loss in service (not including gear loss) in watts, and w is the weight of the motor in lb., excluding gear and gear case. The motor losses in suburban service usually take from $6\frac{3}{4}$ per cent to 7 per cent of the input to the driving equipment, that is motors and rheostats, in the continuous-current system, and from 15 per cent to 18 per cent of this input in the single-phase system. The great motor losses incident to the single-phase system form the

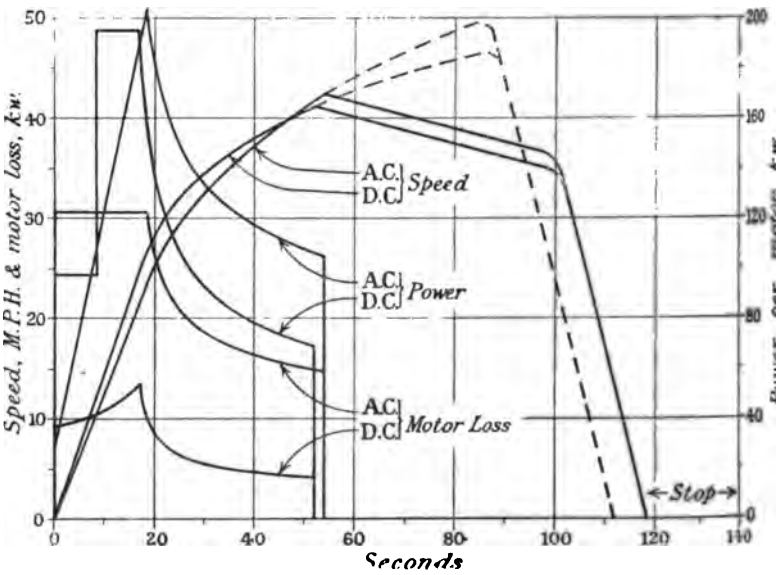


FIG. 5 TRAIN CHARACTERISTICS

foundation of all the objections raised to the use of this system for suburban service.[1]

46 The heating of the motors has always been a limiting feature in the design of equipments for this class of service, and the practicable and desirable means of dealing with it are well understood. The use of forced draft for cooling the motors whilst practicable for locomotives and single cars, is quite out of place on multiple-unit trains intended for suburban service, where, since the equipment

[1]Proc. Inst. E. E., vol. 36, p. 253; also Proc. Inst. C. E., vol. 167, p. 88, and vol. 179, p. 138.

be inspected for hours together, it cannot fail to lead to break-
ıcreasing maintenance charges and causing delays to traffic.[1]
'ig. 5 gives speed, power and motor-loss curves-corresponding
al suburban schedule runs with continuous-current and with
hase equipments, the former of which carries 20 tons per
nd the latter 23 tons. Figs. 6 and 7 show the corresponding

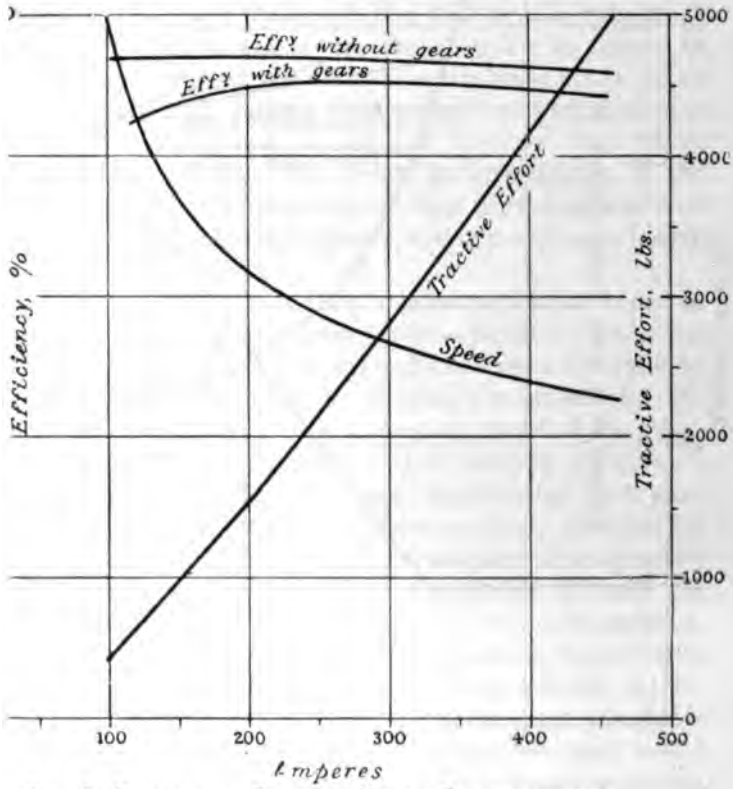


FIG. 6 CONTINUOUS-CURRENT MOTOR CHARACTERISTICS

characteristics. It will be seen that the great difference be-
he systems is in the motor loss, which amounts to 6.75 per cent
ıput in the continuous-current case and to 17.8 per cent in the
hase case. Although both motors are dynamically capable
ing the service, the former alone has sufficient thermal capacity
purpose, the other having to dissipate three times as much
as it can get rid of by natural cooling.

ric Traction on Railways, by Philip Dawson, p. 165.

48 The author has confined his remarks to the subject of suburban electrification, inasmuch as there appears little prospect at present of general electrification of railways in this country. The properties which give to electrical working its predominant advantages in

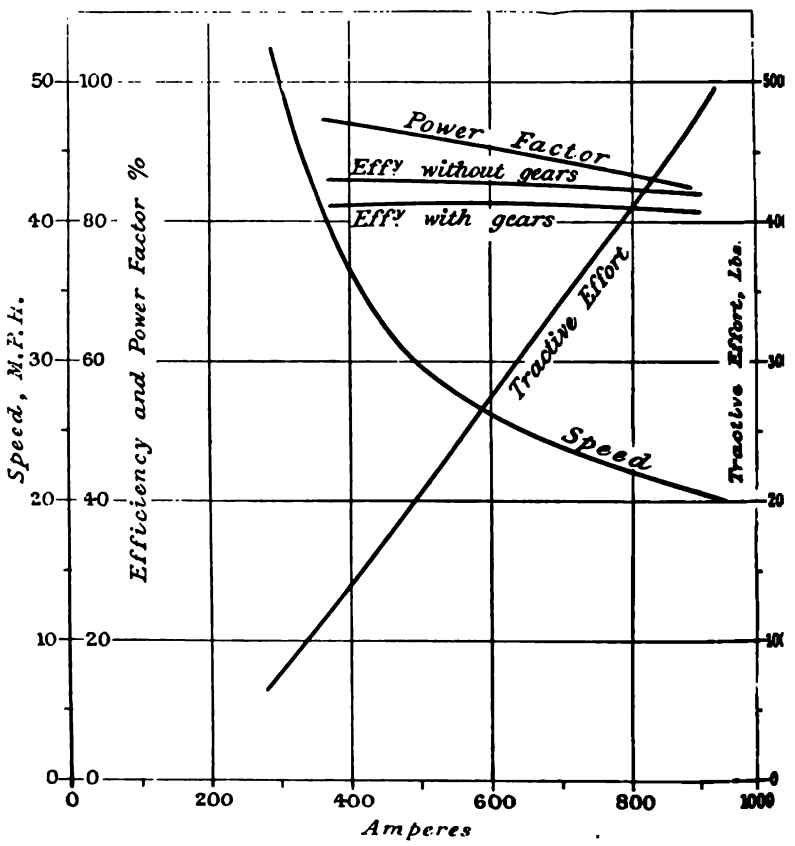


FIG. 7 SINGLE-PHASE MOTOR CHARACTERISTICS

the case of heavy suburban service become of minor importance wh the distance between stops is considerable and the service infrequen This matter was dealt with by Mr. Aspinall in his Presidential addres and having also been recently discussed by the author[2] need n

[1]Proc. I. Mech. E., 1909, pt. 2, p. 425.

[2]Proc. Rugby Engineering Society, vol. 6, p. 47; Electrical Engineer, vol. 4 p. 305.

urther pursued. Whilst it is, perhaps, gratifying to the electrical ıneer to reflect that he can propose means fully competent to k the whole railway traffic of this country and can offer three inct methods of doing it, it is futile as things are to regard the ɔlem of electrification from any other point of view than that of ultimate commercial advantage of the railway companies. The hor's investigations have convinced him that in this country at t the commercial advantage is only demonstrable in general in case of heavy suburban service. Even here it should not be taken granted, for the margin in favor of electrification is by no means rwhelming. This much can be affirmed, however, that where re is any considerable suburban traffic, an investigation of the t of electrification and the economic results of providing improved lities will repay the trouble and expense, and in many cases, justify ceeding with the conversion.

9 It will be understood that the above remarks are intended to ɔly to the electrification of existing steam-operated lines. The e of entirely new railways is different and much more favorable to ːtrical operation. In laying out a new branch to an existing rail- y again, it may be well worth while to consider electrical operation, capital cost of which might be more than saved in the cheaper dbed, since steep grades are much less objectionable on an elec- ːal than on a steam road. Of course, there are likely openings for ıl electrification on existing railways even apart from suburban tems. It might, for instance, be found profitable to work the ıhers on the Bromsgrove incline electrically. It is quite possible, ıin, that where electric power is already available at goods yards l docks, the shunting could be more efficiently carried out by ːcially designed electric locomotives, fed perhaps by a suitable face-contact system, than by steam locomotives, that would m to be uneconomical for such work. For ordinary main-line rk, however, there is at present no indication that the steam omotive can be superseded with advantage in this country.

APPENDIX No. 1

50 Following are references to selected articles, papers, etc., where furth particulars of British Electric Railways can be found:

a CITY & SOUTH LONDON RAILWAY
Electrician, vol. 48, pp. 166, 256, 337, 529, 564, 684, 774; Jour Inst. E. E. vol. 33, p. 100.

b WATERLOO CITY & RAILWAY
Proc. Inst. C. E., vol. 139, p. 56; Tramway and Railway Wo vol. 17, p. 247.

c CENTRAL LONDON RAILWAY
Traction and Transmission, vol. 7, p. 265, and vol. 8, pp. 60 140; Electric Railway Engineering, by Parshall and Hobar

d GREAT NORTHERN & CITY RAILWAY
Electrical Review, vol. 54, pp. 134, 179, 344; Street Railway Jou vol. 23, p. 340.

e BAKER STREET & WATERLOO RAILWAY
Tramway and Railway World, vol. 19, p. 197.

f GREAT NORTHERN, PICCADILLY & BROMPTON RAILWAY
Tramway and Railway World, vol. 20, p. 527.

g CHARING CROSS, EUSTON & HAMPSTEAD RAILWAY
Tramway and Railway World, vol. 22, p. 1.

h LONDON UNDERGROUND RAILWAYS
Street Railway Journal, vol. 25, p. 388.

i METROPOLITAN DISTRICT RAILWAY
Tramway and Railway World, vol. 17, p. 97.

j LONDON, TILBURY & SOUTHEND RAILWAY
Tramway and Railway World, vol. 23, p. 342.

k METROPOLITAN RAILWAY
Electrician, vol. 54, pp. 340, 381, 417, 473; The Engineer, vo pp. 158, 183, 202, 253; Tramway and Railway World, vol p. 325, and vol. 22, p. 204.

l HAMMERSMITH & CITY RAILWAY
Tramway and Railway World, vol. 22, p. 89.

m LONDON, BRIGHTON & SOUTH COAST RAILWAY
Electric Traction on Railways, by Philip Dawson.

n LIVERPOOL OVERHEAD RAILWAY
Electrician, vol. 30, p. 421; The Engineer, vol. 93, p. 284; Electrical Review, vol. 51, p. 20.

o LANCASHIRE & YORKSHIRE RAILWAY
The Engineer, vol. 97, pp. 275, 321, 338, 357, 388; Proc. Inst. M. E., 1909, Pt. 2, p. 423.

p MERSEY RAILWAY
Proc. Inst. C.E., vol. 179, p. 19; Journal Inst. E.E. ,vol. 33, p. 979.

q NORTH EASTERN RAILWAY
Tramway and Railway World, vol. 15, p. 17.

r MIDLAND RAILWAY
Proc. Inst. C. E., vol. 179, p. 47; Tramway and Railway World, vol. 23, p. 437.

No. 1293*b*

THE COST OF ELECTRICALLY-PROPELLED SUBURBAN TRAINS

By H. M. Hobart,[1] London, England
Non-Member

1 Electrical propulsion permits of increased speed and capacity, eves congestion, and increases revenue, for suburban passenger fic, and permits of the retention of steam-locomotive methods for g-distance traffic.

2 Different systems of electrical propulsion of suburban trains y greatly as regards the capital outlay per train and also as re- ls the consumption of electricity per train-mile; consequently in project for electrical working, it is necessary, not only to compare trical with steam locomotive methods, but also to compare rnative electrical methods.

3 Preliminary cost estimations are facilitated by assuming that railway purchases its electricity from electricity-supply companies) themselves own all works up to the distributing system and) supply the electricity in the form in which it is consumed by the n.

4 The chief items of cost, which are different from those en- ed by steam-locomotive methods and which are different with erent electrical systems, are:

a The cost of the electricity.

b The annual charges for the rolling stock.

c The cost of the distributing system (overhead trolley line or conductor rails and the feeders) between the points where the electricity-supply company delivers the electricity, and the trains.

the purposes of the paper the assumption is made, with reserva- is, that item *c* is independent of the particular electrical system

[1]Oswaldestre House, Norfolk Street, Strand, London.

resented at the meeting of The American Society of Mechanical INEERS with The Institution of Mechanical Engineers, London, land, July 1910.

employed, and the estimates are narrowed down to items *a* and *b*, which, for suburban passenger trains, usually absorb some 35 to 40 per cent of the gross receipts.

55 The two electrical systems subjected to comparison are the systems employing series-wound, continuous-electricity train equipments, termed the continuous system, and the single-phase system. Continuous equipment provides, per ton of equipment, 11 h.p. at the axles, averaged over the journey, as against 6 h.p. per ton in the case of single-phase equipment.* In both cases the cost is some £125 per ton of electrical equipment. For a service where trains pass in each direction at intervals of some 12 to 15 minutes, representative figures for the cost of the electricity as delivered to the railway company in the required form, that is, from the sub-stations are: 0.87*d*, per kw-hr. for continuous electricity and 0.70*d*. per kw-hr. for single phase-electricity.

56 Taking into account that the total consumption, after allowing for non-remunerative train movements and for unavoidable departures from the regular time-table, is some 30 per cent greater than the consumption per recorded train-mile, the cost of electricity per recorded train-mile is, for 180-ft. trains, shown to amount, for single-phase trains, to from 10*d*. to 15*d*. per train-mile, and for continuous trains, to from 10*d*. to 13*d*. per train-mile. The lower values are for a 22-mi. per hr. 1-stop per 0.88-mi. service, that is, for a comparatively moderate service; and the higher values are for a 30-mi. per hr. 1-stop per 1.32-mi. service, that is, for a decidedly severe service.

57 The annual charges for the rolling stock for these two services amount to from 8.6*d*. to 10.5*d*. per train-mile for the single-phase trains and to some 6*d*. per train-mile for the continuous trains.

58 The cost of the electricity plus the annual charges for the rolling stock, that is, the sum of the above two items, is, in the case of single-phase trains, some 3*d*. higher per train-mile for the moderate service and some 6*d*. higher for the severe service, than the corresponding costs for continuous trains.

59 Fixing ideas by assuming the gross receipts in these cases to be 50*d*. per train-mile, the single-phase system, compared with the continuous system, absorbs, for the two items in which the selection of the particular electrical system affects the question most greatly, 6 per cent more of the gross receipts in the case of the moderate service and 12 per cent more of the gross receipts in the case of the severe service.

60 The estimates worked out in the paper show that, for suburban passenger traffic, the continuous system has very decided commercial advantages over the single-phase system, and these advantages are greater the more severe the service, that is, the greater the schedule speed and the shorter the distance between stops. This is the precise class of work where electrical methods afford to railways commercial advantages which are unattainable by steam locomotive methods. For services where there are many miles between successive stops and where a considerable time elapses between the passage of successive trains, the use of steam locomotives permits of commercial advantages which are unattainable with any electrical systems comprising the feature of transmitting the energy to the train.

61 *Preliminary Considerations.* The commercial aspects of applying electricity to the propulsion of suburban trains involve many factors and the thorough investigation of any one of these factors requires careful study. In the present paper the author's aim is to focus attention chiefly on the rolling stock, but it must not be inferred that he implies that the other factors affecting the total cost are of minor importance. It is absolutely insufficient to approach the subject of railway electrification from the standpoint that it resolves itself into a mere question of contrasting electric propulsion with steam locomotive propulsion. Were it not for conditions relating to the large amount of capital already invested in steam railways, it is certain that the merits of electrical methods, would, so far as concerns suburban passenger traffic, lead to their general adoption. But the great cities of the world are already very liberally supplied with steam railways which, in addition to much other important traffic, at present handle the suburban passenger traffic for which electrical methods have, on many occasions, been demonstrated to be specially appropriate.

62 Let us however, conjure up the hypothetical case that London is served by all but one of the older of the several great railways now entering it, and which are all of proven necessity, and that the project is mooted of adding this one urgently needed railway. Under these circumstances the author doubts if there would now be found more than a small minority of railway engineers who, in the face of the demonstrated successes of electrical methods of propulsion, would advocate that the suburban passenger service of this new railway should be handled by steam locomotives. The new terminus would probably be designed and equipped so that the suburban traffic would consist exclusively of electrically-propelled trains. It

is equally probable that beyond some 25 to 30 miles from London the through trains would be drawn by steam locomotives. The through-goods traffic would also be operated by steam locomotives. As to whether the long-distance trains should leave the terminus behind steam or electric locomotives is less apparent, and is, furthermore, a matter of secondary importance, since the presence of a certain number of non-stopping steam trains is entirely consistent with the maintenance of an effective service of electrically-propelled suburban passenger trains. Consequently it would not require any drastic alteration of methods gradually to tend more toward steam or more toward electricity for propelling the through trains when traversing the tracks within the 30-mi. radius. This hypothetical case has simply been cited in order to emphasize more forcibly the generally admitted fact that it is no longer a question of whether, in electricity, there has arrived a better agent than the steam locomotive for the handling of suburban traffic. On the contrary, the exclusive though often amply sufficient reason for delay in replacing steam-locomotive methods by electric propulsion, is, so far as concerns the suburban passenger traffic, nearly always related to the large capital expenditure involved in effecting the change. For not applying electrical methods to other classes of railway traffic there is, so far as relates to Great Britain, the best of all reasons, namely, that steam is, at present, in almost all instances, more economical. The presence of frequent tunnels may afford the chief reason for adopting electricity on a given section, owing to the elimination of smoke and steam. But if it is proposed to employ a bare 6000-volt overhead conductor for supplying the trains, the presence of tunnels of small dimensions may afford the most cogent reason for adhering to the steam locomotive. Heavy grades are much more readily negotiated by electrically-propelled trains, and consequently, for mountain lines, there is an additional incentive for substituting electrical propulsion for steam-locomotive methods. In countries where coal is scarce and water power abundant, as, for instance, in Sweden, Italy, and Switzerland, the general electrification of the railways may be a thoroughly sound proposition, but the distinction between the conditions in Britain and in the countries cited is obvious.

63 In view of the circumstances, the question of the relative cost of various electrical systems of operating suburban lines becomes one of great importance. Although it would be premature to deny the claims of certain further systems of electrical propulsion, the two

systems which are, at the present time, chiefly commanding attention, are the systems employing on the trains continuous-electricity motors and single-phase motors respectively. With a view to concentration, only these two systems will be taken into account.

64 The conventional methods which are employed in analysing the expenses of operating steam railways involve, when applied to estimates for the electrical operation of railways, a considerable degree of obscurity and lead to misunderstandings. The obscurity is often intensified by any attempt to adapt these methods, by slight modifications, to the new conditions attending electrical operation. For the particular investigation which constitutes the object of this paper, it will conduce to clearness to break away completely from these conventional methods of analyzing costs. This is the more justified since the paper deals with broad comparisons, leading to broad generalisations. Were it a question of final and detailed estimates the method employed in this paper would obviously be inappropriate.

65 A railway is an undertaking of such magnitude that, with the extensive adoption of electricity for propulsion, it would often be in the interests of economy for the railway to provide and operate its own electricity-supply stations, and thus save the profits which would be included in the prices at which electricity-supply companies would be prepared to sell the electricity. Nevertheless it is electricity-supply companies, and not the railways, which are at present in a position to supply a railway's requirements to best advantage, and in view of the circumstance that any single railway almost always traverses districts served by many different electricity-supply companies, it is highly probable that for some long time to come, at any rate, a railway would, in many cases, be best serving its own interests by purchasing its electricity from electricity-supply companies and municipal electricity-supply undertakings. It is by no means necessary for the author to investigate this question further, but merely to state that in this investigation, he will assume that the railway not only purchases its electricity from independent undertakings, but that it looks to these independent undertakings to provide all transmission lines from the points where the electricity is generated, and also to provide all the sub-stations, thus delivering the electricity at the required points on the railway company's premises in the form in which it is collected by the trolley-bows or rail-shoes carried by the train. The sub-stations are thus the property of the electricity-supply company. The railway is, however, the proprietor of all the cables and structures intermediary between the sub-stations and the

trains. The railway, in that it owns the property on which its tracks are laid, possesses a great advantage over electricity-supply companies since it can construct its transmission line, whether overhead or underground, without conforming to so many sometimes obstructive regulations, and without payment for way-leaves. By coöperation in extending these advantages to the electricity-supply companies from whom it purchases the electricity, an appreciably lower price should be obtained. These structures may consist in an overhead trolley system, or in conductor-rails, together with in either case, the necessary feeders. When the single-phase system is employed, the sub-stations may contain stationary transformers or they may consist simply of buildings provided with high-pressure switch gear for controlling the inter-connections of the various sections of the line. When the trains are equipped with motors operated by continuous electricity, the sub-stations will be more numerous, and they will be provided chiefly for the purpose of housing motor-generator sets transforming the high-pressure polyphase electricity received from the electricity-supply station, into the relatively low-pressure continuous electricity required at the train. The price charged by the independent electricity-supply undertakings will be for the electricity in the form in which it is delivered from the sub-stations, and owing to the greater cost and lower efficiency of the sub-stations when supplying continuous-electricity, the railway will be obliged to pay a higher price for a given quantity of electricity when it is in the continuous form than when it is in the single-phase form. Prices arrived at by experience on a large scale are now quite well agreed upon for electricity in these two forms. While these prices vary greatly according to the price of fuel and various factors of like nature, and while they also vary greatly with the nature of the load, they can nevertheless be estimated with certainty in any particular case. By allocating to the electricity-supply company the burden of providing the transmission system up to the sub-stations, and also the sub-stations, legitimate simplifications are introduced into the calculations, since there are in Great Britain many electricity-supply companies who are prepared to promptly quote prices for electricity as delivered at the outgoing cables from such sub-stations. For given conditions as regards load factor and price of coal and water, the market price of electricity has for some time been quite a definite quantity.

66 Thus, so far as the outlay for electrical apparatus and equipment is concerned, this method of comparison leads us to the definite proposition of estimating the cost of the rolling stock and the cost

ıe structures along the line, intermediary between the sub-stations the trains. While the cost of these structures has, up to the pres- been higher with the single-phase than with the continuous system ıuthor does not propose in this paper to discuss these differences, he will, on the contrary, assume that the outlay for this portion ıe work is the same for both systems. As to the costs of the trains, nates for each system will be made, since in this respect the two ems differ greatly from one another.

To fix ideas, the author will confine his comparisons chiefly to ıs consisting of three double-bogie coaches. It is well known , under reasonably favorable conditions, such trains usually l gross receipts of some 40*d.* to 60*d.* per train-mile. The cost of the tricity required for the propulsion of the trains, together with onable estimates for the capital charges for the trains including outlay for their depreciation, repairs and renewals, make up an 'egate per train-mile which is usually of the order of from 35 to er cent of the amount of the gross receipts. Into the disposition ıe remainder of the gross receipts it is not proposed to enter, since, ng the electrical structures along the line,[1] that is, the equipment :mediary between the sub-stations and the trains, as representing ıame outlay, irrespective of the particular system of electric trac- adopted, the disposition of this remainder will be substantially ıame, whichever system is employed, and hence does not materi- affect the results in a comparison of systems. It is to the appli- ın of that portion of the gross receipts, roughly 35 to 40 per cent ıereabouts, the precise amount of which is seriously affected by ıelection of the service and of the system of electrification, that author will direct his investigations. It may be said that he is y of comparing alternative systems of electrical operation to the lvantage of the interests of electrical operation in general, but he not admit this to be the case. On the contrary, a correct inter- ıation of his results will show that his object is to consecrate each :m to its appropriate purpose, and to admit fully that for long-

[1] This is the only electrical item which is not included in the comparisons, since it will introduce no serious error to take this item as independent of particular electrical system adopted, the author considers it preferable, in investigation, to group it with the various non-electrical items, including profits, which make up the remaining 60 to 65 per cent of the gross receipts, which, directly, are independent of the precise electrical system adopted, though indirectly they may be appreciably affected. For instance, the ın and weight of the train affects the permanent-way outlays.

distance through trains, steam-locomotive methods are superior to any electrical methods as at present developed. For high speeds with frequent stops, while both the single-phase system and the continuous system have long been recognized to be adequate as regards their engineering features, the former entails, as he will endeavor to show in this paper, distinctly greater outlay and distinctly less net earnings. He will also endeavor to show that with decreasing speed for a given distance between stops, or with increasing distance between stops for a given speed, the disabilities of the single-phase system become less acute. The determination of the point beyond which the uses of the single-phase system will conduce to greater net earnings than can be obtained by the system employing continuous electricity at the trains, is, however, not within the range comprised by the subject assigned to the Joint Meeting for discussion, namely The Electrification of Suburban Railways, and hence cannot appropriately be dealt with in this paper. Quite aside from any question of the relative merits of alternative systems, the author would be pleased if the results which he has deduced as regards the cost of the rolling stock and of the electricity consumed in its propulsion, should be found useful in dealing with electric railway investigations.

68 The severity of a train service is a function of the schedule speed and of the distance between stops. For a very severe service, many of the train axles are often driven by motors, while for more moderate services it suffices to concentrate the driving power upon but a few of the axles. In eliminating the locomotive and placing the motors under the passenger coaches, the space available for the motors is rather restricted, and the plan of distributing several relatively small motors on several axles is more often a consequence of this space limitation than of any regard for obtaining greater tractive effort by the greater total weight on the driven axles. Although this latter object is always kept in view, it may be said that even the high accelerations employed on electric railways rarely require so great a subdivision of the driving power as is, for severe services, usually resorted to, owing to the space limitations.

69 *Analysis of Two 150-ft. Trains.* The author proposes first to analyze the design and performance of two 150-ft. trains designed for about the same average output, and similar as regards the capacity and distribution of the electrical equipment. In the two 150-ft. trains which have been selected for this analysis, only two motors are employed, and these drive two of the four axles of a motor coach. Each

of these 150-ft. trains comprises three 50-ft.[1] coaches, of which one is a motor coach and the other two are trailer coaches. Thus out of the twelve axles, only two are driven. The first of these two trains is a type designated *A*, which is employed on the Picadilly-Tube Railway in London and weighs 61 tons; the second is a type designated *C*, which is employed on the Heysham, Morecambe and Lancaster Branch of the Midland Railway and weighs 77 tons. The service for which the 61-ton Piccadilly-Tube train is employed requires a schedule speed of 16.4 mi. per hr, and the runs are of an average distance of 0.45 mi. between stations. The 77-ton Heysham train has a schedule speed of some 31 mi. per hr., and there is an average distance of 4 miles between stations. It might appear at first sight that these two services are not comparable, but brief calculations are given below, showing that the average output to the axles is just about the same in the two cases. Furthermore, the average efficiencies of the two electrical equipments do not differ by more than 5 per cent at the outside. This is also the case as regards the efficiencies in the two cases of 180-ft. trains, examined in a later section of this paper, and with a view to avoiding a discussion of so unessential a matter as a few per cent difference in efficiency, the author has, throughout his comparisons, employed the mean value of 70 per cent. His examinations indicate that in no one of the four cases (that is, the two 150-ft. trains and the two 180-ft. trains) is the average efficiency of the electrical equipment on the train for the services for which the trains are employed greater than 72 per cent or less than 68 per cent; consequently the employment throughout of the value of 70 per cent is amply exact and is in the interests of simplicity. The two particular instances of two-motor 150-ft. trains have been taken because precise data of their design and performance are available, and because, while they are equipped for about the same average output, one train carries continuous-electricity equipment and the other carries single-phase equipment. For the 61-ton Piccadilly train, the output of the equipment, averaged over the entire time, including stops, is 87 h.p.; for the 77-ton Heysham train the corresponding figure is 90 h.p. The total weight of the electrical equipment in the two cases is 8.0 tons and 14.9 tons respectively. This estimate of 8.0 tons is somewhat in excess of the weight usually assigned to the equipment of the Pic-

[1] Throughout this paper, it has been convenient to take as the length of the train the length of each coach multiplied by the number of coaches, that is, the length corresponding to buffers and couplings has not been included.

cadilly-Tube trains. The figure usually given is 7.3 tons, but the author prefers to take 8.0 tons since the weight of auxiliary equipment tends to gradually increase in successive installations. This is because with the development of electrical methods, refinements are introduced which were not deemed necessary in the earlier work. This estimate of 8.0 tons is ample to cover air-compressors and governors, all cables, slate switch-panels, collecting shoes, and shoe-beams for both trucks of the motor-coach, steel-tubing bolts, cleats, etc. The estimate of 14.9 tons is for the Siemens Company's equipment as installed on the Heysham train. In each case the service is that for which the equipment was selected. In both cases, the capacity of the motors is probably sufficiently liberal to permit that the motor-coach, with its equipment, may haul three trailers instead of two, for considerable periods. Indeed four-coach Piccadilly trains have been found by tests to be well within the capacity of the two motors of a single motor-coach. But nevertheless the use of two trailers per motor-coach is, both for the Piccadilly and the Heysham lines, the normal case. In each case the ultimate temperature rise in regular service is of moderate amount. Whereas, in the case of the Piccadilly-Tube train, forced draft is not employed, the motors on the Heysham train are only maintained at a sufficiently low temperature by employing forced draft. Consequently the lightness of the continuous-electricity equipment, as compared with the single-phase equipment of the same average output, is the more marked. It should be further borne in mind that, in endeavoring to keep down their weight, single-phase motors are designed with a higher speed, in revolutions per minute, than has been considered good practice with continuous motors, and the required speed at the train axles is in single-phase trains obtained by the interposition of undesirably high gear ratios. Thus we have: Average output in service per tons of electrical equipment

$$\frac{8.7}{8.0} = 10.9 \text{ h.p. for the Piccadilly train}$$

and

$$\frac{9.0}{14.9} = 6.04 \text{ h.p. for the Heysham train}$$

The calculations are set forth in parallel columns in Table 3. In these calculations, as also in those in Table 4, the values for the energy consumption per ton-mile correspond with the representative values given in Table 9, and represent the consumptions under the conditions of test runs. The question of the additional consumption

v for the conditions of routine service, is introduced in a later of this paper.

Analysis of Two 180-ft. Trains. Having now examined two 150- is composed of one motor coach and two trailers, let us turn ention to two trains for more severe services. The two trains he author has selected for his purpose are each 180 ft. in length each composed of two motor coaches and one trailer coach.

AVERAGE OUTPUT IN SERVICE PER TON OF ELECTRIC EQUIPMENT ON PICCADILLY AND HEYSHAM TRAINS

	Piccadilly Train	Heysham Train
motor-coaches	1	1
trailer-coaches	2	2
ber of coaches in the train	3	3
motors	2	2
ber of axles in the train	12	12
axles driven by motors	2	2
rain, ft.	150	150
rain, tons	61	77
peed, (*a*) mi. per hr.	16.4	31.0
stween stops, mi.	0.45	4
sumption per ton-mile, watt-hr.	93	40
train-mile, (*b*) kw-hr.	5.67	3.08
put per train ($= a \times b$), kw.	93.0	95.6
itput from motors to axles taking average efficiency of equipment as 70 per cent, h.p.	87	90
ectrical equipment, tons	8.0	14.9
itput per ton of electrical equipment, h.p.	10.9	6.04
se two average outputs per ton of electrical equipment	$\frac{10.9}{6.04} = 1.81$	

etrically-equipped rolling stock on the Heysham line comprises three such trains. Their nileage for the year ending June 30, 1909, was only 86,000 miles, or an average of only 79 in per day. At 31 mi. per hr. this works out at only 2½ hr. per train per day. In the analy- er, the author is crediting the Heysham trains with having an equipment adequate to work le speed of 31 mi. per hr. for many consecutive hours. The Piccadilly-Tube trains do this. ay, a single train often maintaining its schedule speed for 18 consecutive hours and cover- time 300 miles.

oach is 60 ft. in length. Each motor-coach is equipped with otors, making up a total of eight motors per train. Thus eight welve axles of the trains are driven by motors, whereas in the mer trains only two out of the twelve axles were driven. The these two 180-ft. trains is of a type which may be designated as which is employed on the Southport line, and the second which designated as *D*, and which is one of the trains now operating South London Elevated Railway. The trains are thus some-

what longer and are much heavier than those which we have examined before. The weights of these two 180-ft. trains are respectively 118 tons and 138 tons. The Southport train runs at a schedule speed of 30 mi. per hr. and the average distance between stations is 1.32 mi. The South London elevated train, which will be designated the S.L.E. train, runs at a schedule speed of 22 mi. per hr., and the average distance between stations is 0.88 mi. The striking similarity of these trains as regards their length (180 ft.), their seating capacity,

TABLE 4 AVERAGE OUTPUT IN SERVICE PER TON OF ELECTRIC EQUIPMENT ON SOUTHPORT AND S. L. E. TRAINS

	Southport Train	South London Elevated Train
Number of motor-coaches	2	2
Number of trailer-coaches	1	1
Total number of coaches in the train	3	3
Number of motors	8	8
Total number of axles in the train	12	12
Number of axles driven by motors	8	8
Length of train, ft	180	180
Weight of train, tons	118	138
Schedule speed (a), mi. per hr	30	22
Distance between stops, mi	1.32	0.88
Energy consumption per ton-mile, watt-hr	96	78
Energy consumption per train-mile (b), kw-hr	11.3	10.9
Average input per train ($= a \times b$), kw	340	240
Average output from motors to axles (taking average efficiency of electrical equipment at 70 per cent), h.p	319	225
Weight of electrical equipment, tons	30	44
Average output per ton of electrical equipment, h.p	10.6	5.12
Ratio of these two average outputs per ton of electrical equipment	$\frac{10.6}{5.12} = 2.07$	

and the proportion of motor and trailer-coaches, has led to the establishment of comparisons between them. But these comparisons have usually been of an utterly superficial nature. It has been said that since in the case of the Southport train the stops are less frequent and the speed is higher, the severity of the service is substantially the same as in the case of the S.L.E. train, and it has been assumed, though altogether incorrectly, that the more frequent stops in the case of the S.L.E. train offset the greater speed in the case of the Southport train. The author has, however, pointed out on various occasions that this is not the case. On the contrary, the power which is required at the axles in the case of the Southport 118-ton train is 42 per cent greater than the power which is required at the axles for the S.L.E.

138-ton train, notwithstanding the 18 per cent greater weight of the latter train, and the power required at the axles, per ton of total train weight, is no less than 65 per cent greater for the Southport service than for the S.L.E. service. Some engineers are doubtless well aware of the erroneous character of the assertions which have been made in this matter, but it is probable that other engineers have unguardedly accepted the assertions, and have concluded that for practical purposes the two services may be regarded as substantially equal in severity.

71 The service performed by the Southport 118-ton train requires of the electrical equipment an output to the axles, averaged over the entire run, of 319 h.p., whereas the relatively much less severe service of the S.L.E. 138-ton train requires an output to the axles of only 225 h.p. The weights of the electrical equipments in the two cases are, however, 30 and 44 tons respectively. The average horsepower output to the axles per ton of electrical equipment, works out respectively at 10.6 h.p. for the Southport train, and 5.12 h.p. for the S.L.E. train. As a matter of fact, the Southport trains operating to the schedule in question, while still comprising two motor coaches, each equipped with four motors, very frequently have two trailer coaches, and it is consequently very conservative to take the three-coach train as representative of the capacity of the electrical equipment of two motor coaches. In the Board of Trade returns for 1908, the electrical train service on the Southport line is given as 1,490,000 train-miles and 5,120,000 car-miles. The average train thus comprises 3.4 coaches, which more than justifies the author's standpoint. Possibly also the S.L.E. equipment has a similar margin of capacity. Whether or no this be the case, it is as well to base the comparisons on the three-coach trains in each case, although this is decidedly less than the normal train for the Southport line, whereas it is the standard type of train operated on the S.L.E. Railway. In Table 4 these calculations are set forth in parallel columns.

72 It will be observed that the average output per ton of electrical equipment varies greatly in the four cases which we have examined, and questions naturally arise as to the cause of these great variations. It might be suggested that the variations are attributable to diverging views as to correct methods of design. As it happens, however, the equipments were supplied by four different manufacturers who are among the half-dozen firms who probably have the greatest experience in the manufacture of electric railway equipments. Denoting the four examples as *A*, *B*, *C* and *D*, we arrive at Table 5.

73 Engineers familiar with the relative standing of the leading manufacturers of electric railway apparatus, are well aware that each of these four firms have resources of such magnitude that they are all on a substantially equal footing as regards ability to produce the best, lightest and cheapest apparatus for the purpose in view. Consequently we must seek some other explanation for the striking difference in the results set forth in Table 5. The two first results are within

TABLE 5 COMPARISON OF AVERAGE OUTPUT

Example	Average Output per Ton of Electrical Equipment, h.p.	Railway	Manufacturer
A	10.9	Piccadilly	B. T. H. Co.
B	10.6	Southport	Dick, Kerr & Co.
C	6.04	Heysham	Siemens
D	5.12	S. L. E.	A. E. G.

3 per cent of each other and the last two results are within 18 per cent of each other. That the S.L.E. equipment works out at only 5.12 h.p. per ton while the Heysham equipment comes to 6.04 h.p. per ton, is satisfactorily explained by the circumstance to which allusion has already been made in the footnote to Table 3, to the effect that the Heysham train only averages (over the whole year) some 2½ hr. of service per day whereas the S.L.E. trains will doubtless average (over the 365 days in the year) at least twice this number of hours of service per day. It is stated that for the S.L.E. line, "the mileage of each train service varies between 250 and 500 miles per day." The mean of the first two results is 10.8 h.p. per ton, and the mean of the last two results is 5.6 h.p. per ton. These two values have the ratio 1.93: 1.00. The reason for this difference in weight of about 2 to 1 is that in the first two cases, that is, the Piccadilly-Tube 61-ton train and the Southport 118-ton train, the equipments are designed for, and operated with, continuous electricity, whereas the last two cases, the Heysham 77-ton train and the S.L.E. 138-ton train, have equipments designed for, and operated with, single-phase electricity.

74 As rough, but representative values, we may take it that for a train equipped with continuous apparatus, the electrical equipment may, in actual service, and for approved overload and heating limits, be loaded up to an average output of 11 h.p. per ton-weight of the equipment, whereas single-phase equipments can only be worked up

ıverage output of 6 h.p. per ton.[1] It has been asserted that hstanding that the single-phase equipment for a train required 'orm a given service, weighs twice as much per horsepower as 'responding continuous equipment, this does not seriously affect al train weight, since the weight of the electrical equipment con- s (it is alleged) only a small part of the total weight of the train. investigate this assertion. In Table 5 the four trains have been ıted as *A*, *B*, *C* and *D*. In Table 6 are given the total train s, the weight of the electrical equipment, and the percentage the weight of the electrical equipment constitutes of the total veight.

TABLE 6 TOTAL TRAIN WEIGHTS

n	Designation of Train	Railway	Length of Train, Feet	Total Train Weight, Tons	Weight of Electrical Equipment, Tons	Percentage which Weight of Electrical Equipment Constitutes of the Total Weight of the Train, Per Cent
us...	*A*	Piccadilly	150	61	8.0	13.1
us...	*B*	Southport	180	118	30	25.4
ase.	*C*	Heysham	150	77	14.9	19.3
ase.	*D*	S. L. E.	180	138	44	32.0

Comparing the 180-ft. trains, that is, trains *B* and *D*, we have ıat the Southport service is much the more severe, yet the ;al equipment of the Southport train only amounts to 25.4 per the total weight, as against 32 per cent of the total weight for ıch less severe S.L.E. service. It should be of interest to ascer- ɔw a train of the *D* type would require to be modified in order uitable to perform the *B* service. This and subsequent calcula- vill be simplified by first working out, for all the trains, the e horsepower per ton-weight of train required for the respective s. This is done in Table 7.

hould be noted that the author is favoring the single-phase system cidedly in crediting it with an average output of 6 hp. per ton, for ıue is only attained in the case of the Heysham trains, which only ; 2½ hr. in service per day, whereas the S.L.E. trains, which do an ; of, say, 5 hr. per day, yield an average output per day of only 5.12 ; ton-weight of electrical equipment.

76 The values in the lowest horizontal line of Table 7 are the real criteria of the severity of the service, and we see that the Southport service requires $\left(\text{since } \frac{2.70}{1.63} = 1.65\right)$ 65 per cent more average power per ton-weight of train than is required for the S.L.E. service. The values in the lower line of Table 7 are, since the efficiency is the same, independent of whether single-phase or continuous apparatus is employed. For the Southport service, there must be provided 2.7 h.p. per ton-weight of train. Since we have seen that, with single phase equipment, we obtain 6 h.p. per ton of equipment, we shall require $\frac{2.7}{6.0} = 0.45$ ton of electrical equipment for every ton of total weight of train. Thus 45 per cent of the weight of the train will consist of electrical equipment.

TABLE 7 AVERAGE H.P. PER TON WEIGHT OF TRAIN

System	Continuous		Single-phase	
Designation of train	*A*	*B*	*C*	*D*
Road	Piccadilly	Southport	Heysham	S. L. E.
Length of train, ft	150	180	150	180
Weight of train, tons	61	118	77	122
Average output during service, h.p.	87	319	90	220
Average output per ton weight of train, h.p.	1.42	2.70	1.17	1.8

77 The motor coaches on the S.L.E. line weigh 54 tons each. O this 54 tons weight of one of these motor coaches, only 22 tons, tha is, only 41 per cent of the total weight of the motor coach is electric equipment, and consequently the motor coach which is at present ru ning the S.L.E. service, even with its motors rewound for the requir speed, would not have sufficient capacity, leaving the same mar as on the present S.L.E. service (Par. 71), to accomplish the Sou port schedule with the same heating of the electrical equipment in the S.L.E. service, much less could a train composed of two mo coaches and one trailer accomplish this schedule with normal heat and with appropriate overload capacity. In order to work the S.L 180-ft. train to the Southport schedule, its electrical equipment n be considerably increased in weight. Let W equal the total we of the S.L.E. 180-ft. train, in tons, when reinforced to render it a quate for the Southport service. Then the electrical equipment n weigh 0.45 W. The weight of the S.L.E. 180-ft. train exclusiv

the electrical equipment, is 138 − 44 = 94 tons. Its revised weight when provided with an equipment enabling it to conform to the Southport service, will consequently be

$$W = 0.45 \times W + 94$$

Consequently we have

$$W = 171 \text{ tons}$$

78 The weight of the electrical equipment must thus be

$$171 - 94 = 77 \text{ tons}$$

and the electrical equipment will be capable of delivering an average output of $6 \times 77 = 462$ h.p. Thus the equipment of the S.L.E. train must be increased, as regards its average output, from the 225 h.p. which sufficed for the S.L.E. service, up to the 462 h.p. necessary in order that it may accomplish the Southport service. This is an increase of 105 per cent. The revised S.L.E. train requires to have 462 h.p. average capacity as against the Southport train's 319 h.p. average capacity, an excess of 45 per cent. This further 45 per cent serves no more useful purpose than to carry over the route the increased weight of expensive electrical equipment made necessary by the use of the single-phase system. The revised S.L.E. train weighs 171 tons as against the Southport train's weight of only 118 tons. Thus the result is, that while both trains have the same length of 180 feet, the S.L.E. train, when altered to be adequate to perform the Southport service, weighs 45 per cent more than the Southport train. Moreover, the revised three-coach single-phase train for the Southport service would have to consist of three motor-coaches, in place of the two motor-coaches and one trailer which sufficed to carry the necessary single-phase equipment to perform the S.L.E. service.

79 Let us next reverse the above process and adapt the Southport train to the S.L.E. service of 22 mi. per hr. and one stop every 0.88 mile. This service requires, as seen from Table 7, only 1.63 h.p. per ton of total weight of train. The weight of 1.63 h.p. of continuous equipment is only $\frac{1.63}{11} = 0.148$ ton. Consequently out of each ton of total train weight, only 14.8 per cent will consist of electrical equipment as against the 32 per cent seen from Table 6 to be required when the S.L.E. service is provided by a train equipped with single-phase apparatus. Let us again represent by W the total train weight in tons. Then the weight of the electrical equipment in tons amounts to $0.148 \times W$. The weight of the Southport train, exclusive of the electrical equipment, is 118 − 30 = 88 tons. Consequently $W = 0.148 \times W + 88 = 103$ tons. The weight of the electrical equipment of the revised

Southport train, that is, of the continuous train capable of working to the relatively moderate S.L.E. service, is only $0.148 \times 103 = 15.3$ tons, or only 51 per cent of the 30 tons weight of the electrical equipment required for the Southport train performing the severe Southport service. Obviously then, were we to operate a 180-ft. train to the S.L.E. schedule, employing continuous equipment instead of single-phase equipment, we should not require two motor coaches, but we should make up our three-coach train of one motor coach and two trailers. The continuous equipment thus weighs only 15.3 tons, or only 34.8 per cent of the 44 tons required for the single-phase train of equal length. It is interesting to note that this continuous-electricity train operating on the S.L.E. service is only required to give an average output of $15.3 \times 11 = 168.5$ h.p. which amounts to only $\left(\frac{168.5}{225} = \right)$ 75 per cent of the average output required of the motors on the single-phase 138-ton S.L.E. train.

80 *Cost Estimations.* A rough but thoroughly representative figure for the cost of continuous equipment for railways is £125 per ton. Single-phase equipment at present costs decidedly more, but for the purposes of this investigation the author will take the cost of the electrical equipment, irrespective of whether it is continuous or single-phase, at £125 per ton. Thus for the four trains under consideration, the costs for the electrical equipment work out as in Table 8.

TABLE 8 COSTS FOR ELECTRICAL EQUIPMENT

Electrical Equipment of One Train	Weight, Tons	Cost per Ton, £	Total Cost, £
Continuous train for..... Southport service.	30	125	3750
Continuous train for..... S.L.E. service.....	15.3	125	1910
Single-phase train for..... Southport service..	77	125	9630
Single-phase train for..... S.L.E. service.....	44	125	5500

As to the cost of the remainder of the train, the estimates will be based on the following data:

81 *Bogie Trucks.* The weight of each motor-truck, including truck-frames, wheels, axles, brake-rigging, etc., will be taken at 6.5 tons, the weight of each trailing truck at 5.5 tons. In both cases, the cost of the complete trucks will be taken at £22 per ton. The weight of all the trucks is:

For a train comprising 3 motor coaches and no trailer (12 driven axles)..39 tons
For a train comprising 2 motor coaches and 1 trailer (8 driven axles)...37 tons
For a train comprising 1 motor coach and 2 trailers (4 driven axles).....35 tons

The cost of the trucks for these three trains is:

Three motor-coaches and no trailer.....£860
Two motor-coaches and 1 trailer.....£815
One motor coach and 2 trailers.....£770

The weight of the three coach bodies, complete with underframes, brake-cylinders, upholstering, etc., is:

Continuous train for Southport service.....118 − 30.0 − 37 = 51.0 tons
Continuous train for S.L.E. service.....103 − 15.3 − 35 = 52.7 tons
Single-phase trains for Southport service.....171 − 77.0 − 39 = 55.0 tons
Single-phase train for S.L.E. service.....138 − 44.0 − 37 = 57.0 tons

82 For an absolutely consistent comparison, these four cases should have all worked out at the same value as regards the aggregate weight of the three coach bodies. They are, however, so nearly identical, varying only 6 per cent from the mean value, that their mean value may be taken as representative for the weight of the coach bodies of a 180-ft. train for this type of service. The mean value is 54 tons, or $\frac{54}{3}$ = 18 tons for each coach body. These coach bodies, complete, may be taken as costing £80 per ton. Thus for all four trains the aggregate cost of the three coach bodies, weighing 54 tons, will be 80×54 = £4320.

83 The costs of assembling, and all further costs, will be taken at £5 per ton of train. These further costs are, consequently, for the four trains:

Continuous train for Southport service.....5 × 118 = £590
Continuous train for S.L.E. service.....5 × 103 = £515
Single-phase train for Southport service.....5 × 171 = £855
Single-phase train for S.L.E. service.....5 × 138 = £690

84 The total costs of the four trains are made up as shown in Table 9.

85 Since these trains have a seating capacity of, roughly, one seat per foot, the two lower horizontal lines in Table 9 also give a fair representation of the relative costs and weights per seat. We see that for so severe a service as that at Southport, the cost of a single-phase train (since $\frac{87.0}{52.6}$ = 1.65) works out to be 65 per cent greater per foot of

length than is the cost of a continuous train. For the much more moderate service of the S.L.E. line, the excess cost of the single-phase train per foot of length is only 51 per cent (since $\frac{63.0}{41.7} = 1.51$), and the percentage continues to fall with every amelioration in the severity of the service.

TABLE 9 TOTAL COSTS OF THE FOUR TRAINS

	Continuous Train		Single-Phase Train	
	For Southport Service, £	For S.L.E. Service, £	For Southport Service, £	For S.L.E. Service, £
Trucks	815	770	860	815
Car bodies	4320	4320	4320	4320
Electrical equipment	3750	1910	9630	5200
Further costs	590	515	855	800
Total cost of train	9475	7515	15,665	11,135
Weight of train, tons	118	103	171	146
Cost per ton	£80.3	£72.7	£91.6	£76.1
Length of train, ft	180	180	180	180
Cost per ft	£52.6	£41.7	£87.0	£61.9
Weight per ft., ton	0.655	0.575	0.95	0.77

86 It is usually preferable to reduce weights and costs to the basis of the weight and cost per foot length of train instead of per seat. Mr. J. R. Chapman, late Chief Engineer of the Underground Electric Railways Company of London, has also advocated the reduction of data to terms of the foot length of train, instead of to terms of per seat, in the following words: "The arrangement of seats in a car has no more to do with electrical working than the color of paint used on the outside. A car will carry the maximum number of passengers if it has no seats at all; it will carry the minimum number if it is fitted with arm-chairs. Somewhere in between these two designs there is a medium which fits the average conditions which the particular railway has to meet, and I think that as cars vary in size, and seating arrangements also vary, the comparison should be made per lineal foot of train, or per square foot of floor devoted to passenger accommodation; probably the latter is the best, as it brings into the calculation the alternative of equipment underneath the car, as on the district, or equipment in a cab, as on the tubes; the latter system reduces passenger accommodation but costs less for maintenance. Otherwise it is very difficult to effect comparisons, for not only have we to take into account the varying composition of trains as regards first and third

ss carriages, but there is the further consideration that the policy of lways differs considerably as to the floor space and elbow room which allotted to each passenger. Since, however, the average value of the its per foot for representative passenger trains of mixed composi- n rarely varies much from unity, the values of the weight and cost foot enable us to readily make mental calculations, as occasion uires, of the corresponding weights and costs per seat. It is pref- ble, in all cases, to take the weights of the trains themselves, and to ve out of consideration the weights of the passengers. Table 10, ing the number of seats per foot of overall length of train for several ical trains, will be interesting, as bearing upon this point.

TABLE 10 NUMBER OF SEATS PER FT. OF OVERALL LENGTH OF TRAIN

Railway	Composition of Train M = Motor-Coach T = Trailer-Coach	Number of Seats			Length of Train in Ft.	Seats per Ft. of Overall Length
		3rd Class	1st Class	Total		
thport	(a) $2M + 2T$	138	132	270	240	1.13
	(b) $2M + 2T$	218	66	284	240	1.18
sham	$1M + 2T$	.....	.....	180	150	1.20
ey	$1M + 1T$	64	46	110	120	0.92
th Eastern	$2M + 1T$	116	70	186	171	1.09

37 *The Cost of the Energy Consumed at the Train.* We have now luced fairly definite values for the weights and costs of the rolling ck. The component of the total cost represented by the electricity sumed by the train is also fairly definite for a given service. The sumption at the train is for a given service about the same per -mile whether the electrical equipment be continuous or single- se. The values in Table 11 afford a reasonable basis for estimat- the consumption at the train per ton-mile of actual performance, en the train is handled by a fairly experienced driver and when it is ning strictly to its time table, and over a well built, fairly straight l level permanent way. Although quite practicable variations in acceleration and braking may easily occasion variations of 10 per t or more in the energy consumption at the train, nevertheless the ues in Table 11 are representative of the customary results obtained ler the conditions stated. In the author's opinion the energy sumption per ton-mile is, for frequently-stopping trains, very ch less dependent upon the weight and length of the train than

is generally believed. It would be too irrelevant to the present dis cussion to enter upon the consideration of this point further than t state that the energy-consumption values in Table 11 are consistent fo test runs with trains coming within the range of lengths and weigh considered in this paper.

88 In the case of passenger trains it is preferable for uniform ity's sake to estimate the ton-mileage on the basis of the weight the empty train. The unrecorded ton-mileage corresponding to t weight of the passengers carried, together with that corresponding shunting operations and other non-remunerative running, as w as the increased consumption on occasions when the time table disarranged, will usually bring up the total consumption at the tr to a value some 30 per cent greater than the values given in Table This increase is only in small part due to the weight of the passeng since with average loads, the weight of the passengers rarely increa the weight of the train by more than some 5 to 6 per cent. In following estimates the author will take the consumption of electri at the train as 1.30 times the values in Table 11. To simplify investigation he will not go into the question of whether the rail provides its own generating plant or purchases the electricity fro

TABLE 11 ENERGY CONSUMPTION IN WATT-HOURS PER TON-MILE FOR VARIOUS VALUES OF THE DISTANCE IN MILES BETWEEN STOPS SET FO AT THE HEADS OF THE VERTICAL COLUMNS, AND FOR 20-SEC. STOPS

Schedule Speed in mi. per Hr.	0.5	0.6	0.7	0.8	0.9	1.0	1.25
15	68	58	50	....	.....	.....	.....
16	78	66	56	50	.....	.....	.....
17	93	76	63	55	50	.....	.....
18	114	90	73	62	55	48	.....
19	.....	104	83	70	60	53	.....
20	.....	.....	94	78	66	58	47
22	.....	.....	.....	95	77	67	54
24	.....	.....	.....	.....	90	83	65
26	.....	.....	.....	.....	.....	100	78
28	.....	.....	.....	.....	.....	.....	93
30	.....	.....	.....	.....	.....	.....	104

supply company; but he will merely assume that the electri is obtained at a total cost of 0.65*d.* per kw-hr. as delivered to the stations. Owing to the greater loss in transformation at the stations and the greater cost of the sub-stations, in the continuou contrasted with the single-phase system, he will take the cost of electricity as delivered from the sub-stations at 0.70*d.* per kw-hr

he single-phase system, and at 0.87*d.* per kw-hr. for the continuous ystem. These amounts cover all outlays, both capital and operating, ıp to the outgoing cables from the sub-stations. The losses in the ransmission system from the sub-stations to the trains are of but mall amount in either system. To allow for them he will take the ost of the electricity delivered at the trains as 0.72*d.* per kw-hr. for he single-phase system, and 0.90*d.* per kw-hr. for the continuous sys-em. These last increases in the cost simply allow for the electricity asted in the process of being conveyed from the sub-stations to the rains, and do not allow for the capital and maintenance charges for he cables and the conductor-rails or overhead structures by means of hich the electricity is conveyed from the sub-stations to the trains. he two figures of 0.72*d.* and 0.90*d.* per kw-hr. respectively are horoughly representative as regards their relative values, though their ctual values, while representative, will vary considerably according o many local circumstances.

89 Furthermore these values are only applicable for the conditions f a suburban service of passenger trains where the trains in each direc-ion run, as an average, at intervals of some twelve to fifteen minutes luring some sixteen to twenty hours per day. For a less intense-ervice, the price for continuous electricity will exceed that for single hase electricity by a greater percentage, since the cost of the sub-tations will constitute a larger item, and the all-day efficiency of the ub-stations will be less. If, on the contrary, the trains run at inter-als of only some three to six minutes, then also the relative figures f 0.72*d.* and 0.90*d.* at the trains are not applicable; 0.69*d.* for the single-hase system, and 0.83*d* for the continuous system, would then be nore appropriate, the latter in this case exceeding the former by only 20 per cent as against 25 per cent in the case of the twelve to fifteen ninutes' service. This is because, while the cost of the electricity, as lelivered at the trains, in the cases of both systems, decreases with the ntensity of traffic, the decrease is a greater amount for the continu-ous system, owing to the better load-factor at the sub-stations and he consequent considerable reduction in the capital charges and oper-ating expenses of the sub-stations. For his further comparisons, nowever, the author will take the figures of 0.72*d.* for the single-phase ystem and 0.90*d* for the continuous system for the cost of electricity per kw-hr. delivered at the trains.

90 With these data, we may now estimate the cost of the electri-city consumed by 180-ft. trains operating to the Southport service (as an instance of a severe service) and to the S.L.E. service (as an in-

stance of a much more moderate service). The price actually paid for the electricity for the S.L.E. trains is, at present, decidedly higher than the figures here taken, but the fairly high price in that instance is probably, to some extent, incidental to the experimental nature of the undertaking at this stage. It is well known that in most districts there would, under the conditions already indicated, be reasonable profit in supplying railways with electricity at the prices stated, and hence it is only on the basis of such prices that the comparisons will lead to useful results.

91 To fix ideas, it can be taken that the author's figures relate to a hypothetical road so situated that his prices for electricity are applicable, and have been quoted, and that the engineers of this road are engaged in determining

a Whether to use the continuous or the single-phase system.

b The schedule speed to be provided on various sections of line with various distances between stations.

TABLE 12 DATA FOR COMPARATIVE RESULTS OF FOUR TYPICAL CASES

Designating Number	Length of Train, Ft.	Average Distance Between Stations, Mi.	Schedule Speed, Mi. per Hr.	System
I	180	1.32	30	continuous
II	180	1.32	30	single-phase
III	180	0.88	22	continuous
IV	180	0.88	22	single-phase

92 Prior to making some detailed estimates, the engineers of this railway will first arrive at some general comparative results, as follows

93 Let the comparison relate to four cases, I, II, III and IV. The general particulars of these cases are set forth in Table 12.

94 Out of the 8760 hours in the year, it is rarely practicable, on other than tube railways or railways providing the class of service associated with tube railways, to attain (for suburban passenger trains) to much more than 2000 hours of actual service on the line. Usually the figure is decidedly less than 2000 hours.

95 For a schedule speed of 30 mi. per hr. the profitable mileage per train per annum, on the basis of 2000 hours, works out at 60,000 miles, and for a schedule speed of 22 mi. per hr. it works out at 44,000 miles. Under the conditions of actual service, there will not be so much difference as this, between the annual average mileage per train, for these two schedules. The more the service conforms to the condi-

ions of a tramway service, the more uniform and continuous will be he sequence of trains; consequently, for the 22 mi. per hr. case the uthor will take the annual average mileage per train at 48,000 miles nstead of the above 44,000 miles, and for the 30 mi. per hr. case he vill take the annual average mileage at 54,000 miles instead of the above 50,000 miles.

96 The total cost of electricity per annum per train is obtained as hown in Table 13.

TABLE 13 TOTAL COST OF ELECTRICITY PER ANNUM PER TRAIN

chedule speed, mi. per hr.	30		22	
istance between stops, mi.	1.32		0.88	
esignating number	I	II	III	IV
ystem	continuous	single-phase	continuous	single-phase
eight of train (from Table 9), tons	118	171	103	138
et consumption of electricity at train in watt-hr. per ton-mile (from Table 11)	96	96	79	79
et consumption of electricity at train in kw-hr. per train-mile	11.3	16.4	8.2	10.9
iles per train per annum	54,000	54,000	48,000	48,000
et consumption per train per annum (kw-hr)	610,000	886,000	394,000	523,000
ross consumption per train per annum (= 1.30 × net consumption) kw-hr	793,000	1,150,000	512,000	680,000
ost of electricity delivered at train per kw-hr., *d*	0.90	0.72	0.90	0.72
otal annual cost per train for electricity, £	2970	3450	1920	2040
otal annual cost per train-mile for electricity, *d*	13.2	15.3	9.6	10.2

97 Questions relating to the depreciation, maintenance and renewals of trains are of so wide-reaching a nature that it would be inappropriate to deal with them in this brief paper. For comparative purposes, however, the author does not believe that the instructiveness of his results will be impaired, if he takes at the rough figure of 15 per cent of the cost of the rolling stock, the annual charges for interest, depreciation, repairs and renewals. He will term these the annual charges for capital, depreciation, repairs and renewals per train, and as a check to indicate their general reasonableness, he will, in Table 14, also work out the corresponding values per train-mile.

98 In Table 15, are brought together the results of Tables 13 and 14.

99 Amongst the many and large remaining costs, there are none in which the adoption of the continuous system will entail greater costs per train than are incurred with the single-phase system.

100 It is well known that the gross receipts for three coach

TABLE 14 VALUES PER TRAIN MILE

Schedule speed, mi. per hr	30		22	
Average distance between stops, mi	1.32		0.88	
Designating number	I	II	III	IV
System	continuous	Single-phase	continuous	single-phase
Total cost of train, from Table 9, £	9475	15655	7515	11355
Percentage taken for obtaining annual capital charges, per cent	15	15	15	15
Annual charges per train for capital depreciation repairs and renewals, £	1420	2350	1130	1700
Annual charges per train-mile for capital depreciation, repairs and renewals, *d*	9.31	10.43	5.65	8.55

trains on services of this character, are usually of the order of from 40*d*. to 60*d*. per train-mile. Let us fix our attention on a case where the gross receipts are 50*d*. per train-mile. It is evident from the results in the lowest horizontal line of Table 15 that in such a case, whatever be the net profits, they will be less if the single-phase system is used than if the continuous system is used. The percentage of the gross receipts which could be set aside as profits, would for the 30 mi.

TABLE 15 RESULTS OF TABLES 13 AND 14

Schedule speed, mi. per hr	30		22	
Average distance between stops, mi	1.32		0.88	
Designating number	I	II	III	IV
System	continuous	single-phase	continuous	single-phase
Total annual cost per train, for electricity, £	2970	3450	1920	2900
Annual charges for capital, depreciation, repairs, and renewals, per train, £	1420	2350	1130	1700
Sum of above two annual outlays, per train, £	4390	5800	3050	4600
Cost per train-mile, for electricity, *d*	13.2	15.3	9.6	13.2
Annual charges for rolling-stock, per train-mile, *d*	6.31	10.43	5.65	8.55
Sum of above two outlays per train-mile, *d*	19.51	25.73	15.25	18.75
Amount by which the single-phase train costs more per train-mile than the continuous-electricity train, *d*		6.22		3.5

per hr., one-stop per 1.32 mile service, be $\frac{6.22 \times 100}{50}$ = 12.45 per cent greater with the continuous than with the single-phase system. For the 22 mi. per hr., one stop per 0.88-mile service, they would still be greater by $\frac{3.5 \times 100}{50}$ = 6.7 per cent. It is common knowledge that

ıurban traffic is at present very unremunerative, although this is
; always obvious from balance sheets where the profits shown are
ıally very largely from main-line and goods traffic. Confining our
ention to the suburban traffic, it appears that while there may be a
' services in which the margin in favor of electrification is great
ıugh to stand the higher cost of the single-phase system, there are
ny in which the great difference which the author has shown as
ɜting between the two systems would make all the difference between
ɑmercial success and commercial failure.

01 The subject is a large one with many important aspects. This
estigation, however, clearly shows that the selection of the elec-
:al system and also the determination of the service to be provided
regards schedule speed, distance between stations and intensity of
ffic, are all matters demanding the most careful attention and that
:y are interdependent. It is evident from the nature of the case,
illustrated by the problems the author has worked out, that the
re severe the service and the more intense the traffic, the greater is
: superiority of the continuous system. But it is also demonstrated
ıt even for systems for such moderate severity as 22 mi. per hr. and
ɜ stop per 0.88 mile, and even when the intensity of traffic is only
ɜ train every 12 to 15 minutes in each direction, the superiority
the continuous system is still very substantial. It is, however, pre-
ely for intense traffic and for severe services, that is, for services
ɔeeding the limits amenable to steam-locomotive methods, that
ctricity is preĕminently applicable.

102 A point of considerable interest, disclosed by a comparison of
: values in the penultimate horizontal line in Table 15, is that,
th the continuous system, the components of the total cost per
ın-mile, which he has considered, are 28 per cent greater (since
$\frac{.51}{.25} = 1.28$) for the 30 mi. per hr., one stop per 1.32 mile service,
ın for the 22 mi. per hr., one stop per 0.88 mile service, while with
: single-phase system, the cost per train-mile is 37 per cent greater
nce $\frac{25.73}{18.75} = 1.37$) for the former than for the latter service. This
ınother point of view from which the greater appropriateness of the
ıtinuous system for severe services is apparent.

103 With the object of basing his comparisons on thoroughly au-
'nticated cases, the author has taken for the continuous-electricity
vices, roads employing pressures of some 600 volts at the trains.

There are, however, now a considerable number of roads employ a pressure of 1200 volts with conspicuous success; indeed, in some these instances, single-phase equipments have been replaced by 12 volt continuous-electricity equipments. As early as 1904 the auth urged the advantages of doubling the customary pressure for conti ous-electricity traction systems, and based his comparisons on precise lines which are now being so successfully adopted. Upward a dozen roads have now adopted the 1200-volt continuous-electri system of traction. This system effects distinct economies over 600-volt system and very appreciably accentuates the contrast tween the continuous-electricity system and the single-phase syst

[1] Electrical Review, vol. 54, pp. 693–765.

No. 1293c

CONOMICS OF RAILWAY ELECTRIFICATION

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104 National prosperity and importance are largely proportional to cilities for intercommunication, and since overland transportation to so large an extent dependent on railways any development oviding for better railway service is of paramount importance. eam locomotives and electric motors are the two recognised means applying power which are available for practical railway require- ents. The fundamental principles which underlie the problem train movement are the same in either instance, but a true com- arison of their relative advantages can be made only by a study each particular method.

105 Much that has been written has treated the subject of electrifi- ation of steam railways from the general standpoint of averages, ut unfortunately the economic application of electricity is not subject for generalization—unfortunately, because averages re convenient and usually available, but often lead to erroneous onclusions, either for or against electrification. It is a mistake to ssume that the average of the expenses for the entire railroad repre- ents the actual expense for the particular conditions usually existing n the division under consideration.

106 On account of the investment already incurred, and because he question is usually one of determining comparative results, the lectrification of an existing steam railway is a more complex problem han the electrical equipment of a new road.

107 Electrification, like any other engineering work, involves an in- estment against which there will be a fixed charge for interest and a iability of depreciation. The interest is a constant and permanent harge which must be met irrespective of any economy which may e secured by intelligent operation. The subject of depreciation is

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receiving more attention than formerly, the tendency having been to make the operating expenses cover this charge. However classified, the depreciation charge must be accounted for, and it is directly influenced by the character of the equipment with respect to reliability, durability, and capacity to provide for future requirements.

FIG. 8 THREE-PHASE LOCOMOTIVE USED AT THE CASCADE TUNNEL OF THE GREAT NORTHERN RAILWAY

Trolley Voltage	[illegible]
Frequency, cycles	25
Total weight, lb	[illegible]
Weight on drivers, lb	[illegible]
Maximum rated drawbar pull	77,000
Continuous rated drawbar pull	[illegible]
Speed, mi. per hr	[illegible]
Duty—Three units to haul 1500-ton train up 2.2 per cent grade	

108 The utilization of higher trolley potentials, made possible with direct current by the development of the commutating-pole motor, and with alternating current by the development of the single-phase motor; the higher speeds of rotary apparatus in the sub-stations; and the development of the steam turbine, have effected a material reduction in the investment required and the cost of operation.

109 The different methods of electrification applicable in any instance should be carefully analyzed with regard to interest, depreciation and operating expense, and only the net result should be

FIG. 9 TRUCKS FOR THREE-PHASE LOCOMOTIVE, GREAT NORTHERN RAILWAY

given consideration in determining the class of equipment. In this connection it is well to bear in mind that the expenditure is a lump sum which can be accurately determined, while depreciation and operating expense can be only approximated. Reference to the corresponding items of expense on railways operating under conditions comparable to those of the line to be electrified, will supply the most reliable figures. Future traffic developments must not be overlooked and the type of initial electrification should be selected with due regard to the ultimate requirements.

110 There would undoubtedly be an advantage in having the character of the energy supplied to the contact conductor uniform, but this is out of the question on account of the great difference in the requirements of specific conditions, such as congested urban or suburban service and comparatively infrequent trunk line train movements.

111 The sub-station and rolling stock may be equipped for operation with direct current or alternating current, single-phase or three-phase, and what is commonly spoken of as "the system" usually refers only to that part of the general scheme of electrification which comprises the sub-station and rolling stock equipment. There are exceptional

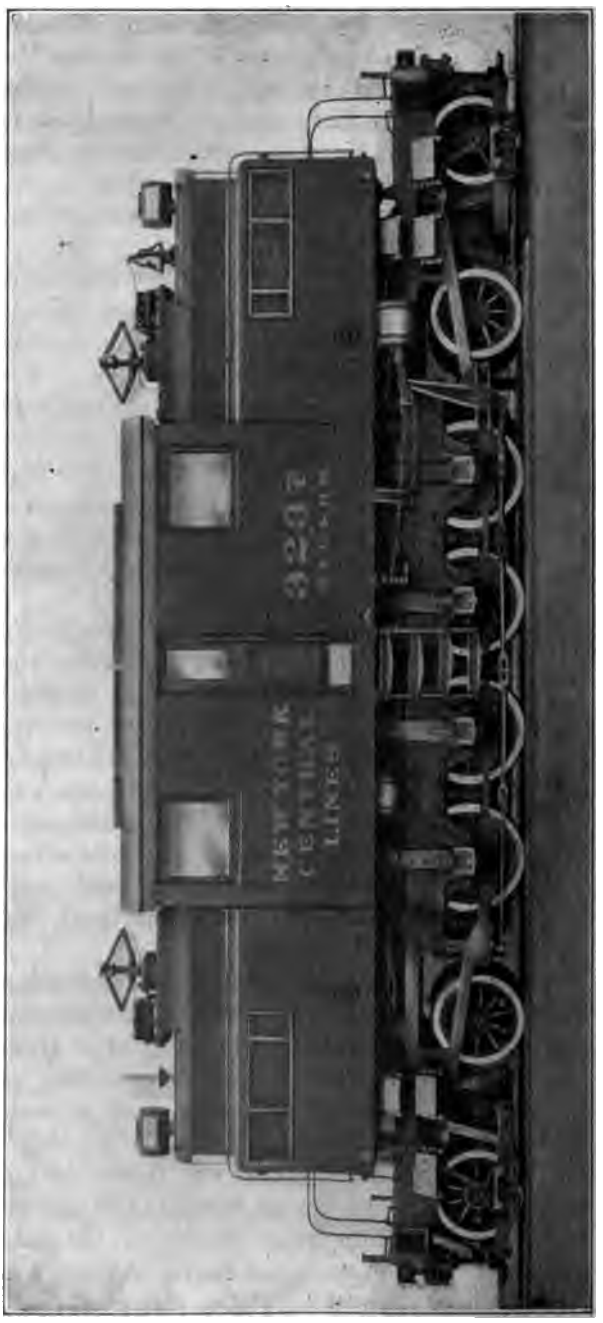
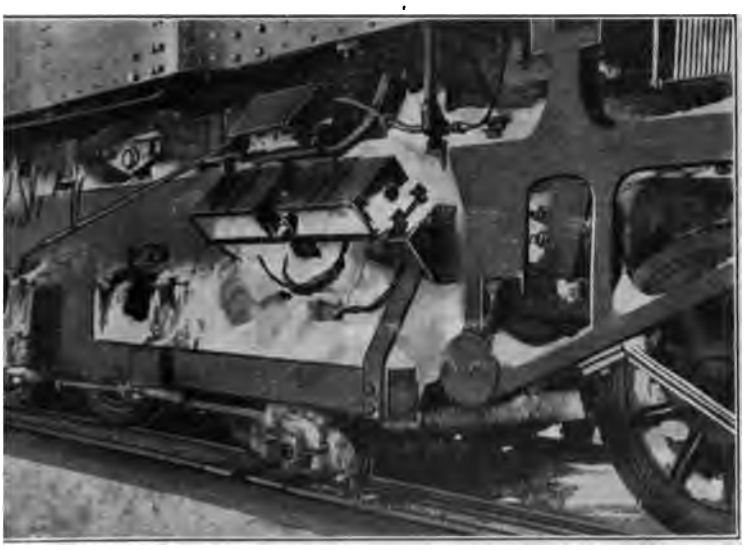


FIG. 10 DIRECT-CURRENT LOCOMOTIVE USED IN THE NEW YORK CENTRAL ELECTRIFICATION AT NEW YORK.

Voltage, D. C.	660
Total weight	230,000
Weight on drivers, lb	141,000

s where the power station and transmission lines have direct tion to the rolling stock equipments; but with the development lternating-current transmission, this is less frequently the case ı it was a number of years ago when 600-volt power stations)lied power directly for the operation of 600-volt motors.

2 The development of apparatus for higher voltage direct cur- has so far increased its scope that direct current at either 600 ıge or higher may be considered the most economical for city interurban service, and for the electrification of steam railways ·e the density of traffic is sufficient to require a relatively large



1 PORTION OF A NEW YORK CENTRAL LOCOMOTIVE AFTER RUNNING THROUGH SNOW

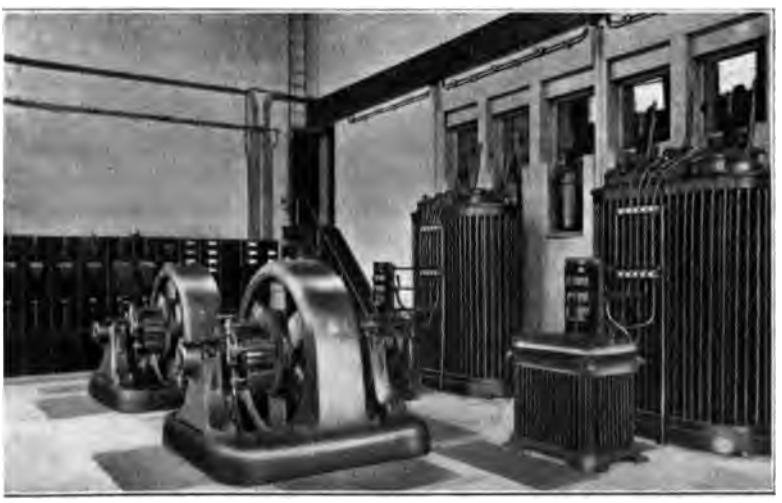
tment for rolling stock, as compared with that required for the dary distribution system and the sub-station apparatus.

3 Single-phase and three-phase rolling stock equipments are cable only to exceptional conditions. The reason for this is the er first cost of such equipments. This is especially true when aring single-phase with direct-current. The type of equipment on the rolling stock may well be a more important factor in the)my of investment and operation than the scheme of power bution.

FIG. 21 TYPICAL AMERICAN INTERURBAN CAR, WEST SHORE RAILROAD

114 Under the conditions which exist in America, direct-current ıd single-phase are applicable to either level or grade work; while ıree-phase will probably be limited to the latter where its regenera- ve feature of returning energy to the line may be of value. The lative economy of the different systems of electrification is depend- ıt on the density of traffic and the character of power available, ther than on the length of the railway.

115 In cases where purchased power is used, or is depended on ; a reserve, the frequency of the current supplied by the power ›mpany will have a bearing on the cost of sub-stations, and will ıus affect the choice of the system. For direct-current operation,



ı. 13 INTERIOR OF 60,000-VOLT INTERURBAN SUB-STATION, CLARKS MILLS, N. Y.

tary apparatus is used for converting the alternating into direct rrent, and the frequency of the supply is therefore relatively unim- ›rtant. For single-phase operation under the usual conditions, frequency of not more than 15 cycles is desirable; and to provide is frequency, rotary frequency-changers are as necessary as are tary converters in the case of direct current, since the frequency existing power companies ranges from 25 to 60 cycles.

116 With power supplied at the proper frequency for single-phase ›eration, permitting the use of static transformers and dispensing ith frequency changers, the amount of energy required for a given

trunk line service is in many cases nearly the same as for direct current, the greater weight of the equipped rolling stock, and the lower efficiency of the single-phase equipments, offsetting the rotary converters and trolley-line or third-rail losses of the direct current.

TABLE 16 REASONABLE VALUES FOR TRUNK-LINE SERVICE

SUB-STATIONS

	600 v. D. C.	1200 v. D. C.	11,000 v. 1-Phase	11,000 v. 3-Phase
First cost per kw., complete	$26	$28	$11	$12
Comparison of installed kw., %	200–250	100–125	100	100–125
Load factor, machines in service, %	20–40	35–70	40–80	30–60
Average efficiency, %	78–88	87–92	97–98	97–98
Yearly operation and maintenance, each station	$5000	$5000	$2500	$2500

CONTACT CONDUCTORS[1]

	Third Rail		Overhead	
First cost, per mile	$5000 to $7000	$5500 to $7500	$3500 to $7000	$4500 to $8000
Efficiency, %	88–92	90–96	93–97	96–97
Maintenance per mile per year	$75–$125	$100–$150	$100–$200	$125–$250

ROLLING STOCK[2]

	600 v. D. C.	1200 v. D. C.	11,000 v. 1-Phase	11,000 v. 3-Phase
LOCOMOTIVES				
First cost, each	$44,000	$47,500	$64,000	$55,000
Weight, tons (2000 lb.)	125	125	160	160
Average efficiency, locomotive wheels to trolley, %	85	85	79	81
Maintenance per locomotive per mile, cents	4	4	8	5
MOTOR CARS (COMPLETE)				
First cost, each	$12,000	$13,500	$20,000	.....
Weight, tons (2000 lb.)	43	44	54	.....
Average efficiency, wheels to trolley	82	81	73	.....
Maintenance per car mile, cents	2	2.2	3.5	.....

[1] Variation in cost of third rail due to different weights of rail which may be required. Variation in cost of overhead due to variation in the class of construction, such as with wooden poles or with steel bridges.

[2] Other weights of locomotives will cost more or less about in proportion to their weights. With gearless direct-current locomotives, the average efficiency of locomotive wheels to trolley is approximately 88 per cent.

CONDITIONS DETERMINING RAILWAY EQUIPMENT

.7 The principal conditions which determine railway equip-
it are:

DATA SHEET

a Profile of road.
b Transportation required, *i.e.*, weight of trains or seating capacity of cars.
c Frequency of trains.
d Length of individual runs or distance between stops.
e Schedule required.
f Length of railway to be electrified.

.8 In the selection of the electrical system best adapted to a
icular set of conditions there are three items to be considered:
sub-stations, (*b*) contact conductors, (*c*) rolling stock. A com-
son of these items determines the relative economic values of
systems. There are certain features under each of these items
h may properly be examined. For trunk-line service the values
able 16 will be found within reasonable limits for the usual require-
ts.

9 We will consider briefly the effect of changes in the Data
t items (Par. 117):

a *Profile:* From a level country to a limiting grade of 1 or 1½ per cent there will be little difference in the relative values of the systems. With steeper grades the conditions will be more favorable for alternating current.
b *Traffic Requirements:* Heavy individual train units favor the alternating-current system with exception of the locomotives; light trains or multiple-unit operation favor the direct-current system.
c *Frequency of Trains:* Infrequent service with a relatively small number of locomotives favors the alternating-current, frequent service the direct-current. With increase in number of trains, the direct-current systems gain relatively faster than the alternating-current in economy of operation, due to relatively decreased sub-station operation, increased sub-station efficiency, and lower cost of equipment maintenance. It is therefore well to consider what the ultimate traffic density may be and select the system best suited to meet these requirements.

d, e Distance between Stops and Schedule Required: Variation in these will not affect the relative value of systems unle extreme requirements, such as high schedule speed wit short runs, make the use of direct current imperative.

f Length of Road: For a similar character of service throughou the railroad may be of any length without affecting th relative desirability of the various systems. What suitable for the first fifty miles will be equally suitable f any extension.

An examination of these variables will show that a change in the co ditions to be met will radically change the relative economic val of the systems of electrification.

120 The single-phase system, by reason of the apparent simp city of its elements and the utilization of higher potential for t contact conductor than is possible with direct current, is u mittedly very attractive. There is the other side of the questio that it is impossible to build a single-phase commutating motor co parable in first cost and maintenance with a direct-current mot Over this subject of alternating-current single-phase vs. dire current systems there has been a great deal of controversy. It our opinion that comparative results obtained up to the pres time are in favor of direct-current.

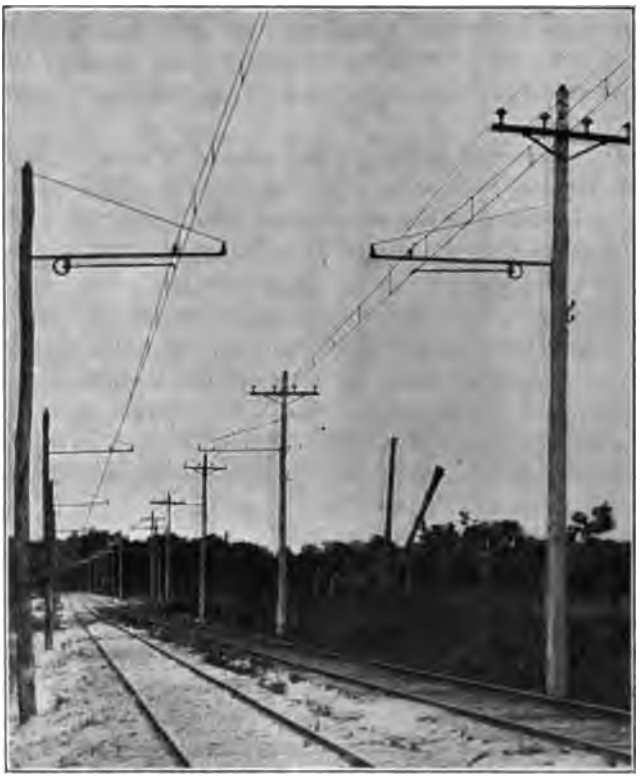
121 Desirable as would be a standard system for all classes service, we cannot hope to establish such a standard should it impo an additional expense without adequate return. A summing up all the elements of each electrical system will generally lead to a de nite showing of which system is most desirable to meet specific co ditions. For trunk line service a higher potential than 600 vo will unquestionably be used; 1200 volts direct-current will pro economical in some cases, but a still higher voltage is required provide economically for the heavier intermittent service. Whet this potential will be 1800 or 2400 volts direct-current or 11,0 volts alternating-current cannot be settled arbitrarily.

INTERURBAN RAILWAYS

122 Let us consider the interurban railway situation in the Unit States, particularly in regard to the various available schemes electrification. These are, 600-volt direct-current, 1200-volt dire

ent, and single-phase, the three-phase being debarred on account ıe complications of the necessary double overhead-distribution em.

3 The application of single-phase to new projects has been tically abandoned, there having been but one or two new installa-



14 Typical American Overhead 6600-Volt Single-Phase Interur-an Trolley Line, Baltimore & Annapolis Short Line, Annapolis, Md.

s in the last three years. This arrested development of a system ch for a short time held forth considerable promise, has been ıght about by a general recognition of its limitations. Experi- has shown these to be:

a Excessive weight of rolling stock.
b Excessive cost of rolling stock.

c High cost of equipment maintenance.
d Increased power consumption.
e Rapid depreciation of motor.
f Rapid depreciation of car bodies and trucks.
g Increased cost of maintaining track and road-way.

Moreover it is recognized that any interurban road in the United States must be capable of operating over existing city tracks from 600-volt direct-current trolley, a condition which hampers the single-phase system on account of increased complications in the control system.

124 For interurban railways a potential of 1200-volt direct-current has been selected, because with the motors wound for 600 volts the car may be operated at the same speed from either 600 or 1200-volt trolley, by connecting the motors all in parallel for 600-volt operation, and two in series with two groups in parallel on a 1200-volt section.

125 To show clearly the relative merits of the systems we have made an analysis of an interurban railroad 100 miles long with cars in each direction every hour. This condition represents practically the minimum car requirements in the United States, and is therefore favorable to the single-phase. It is obvious that any increase in traffic density will be relatively more favorable to the direct-current system on account of the lower first cost of cars, lower car maintenance and relatively lower cost of sub-station operation.

126 Assume a typical interurban condition:

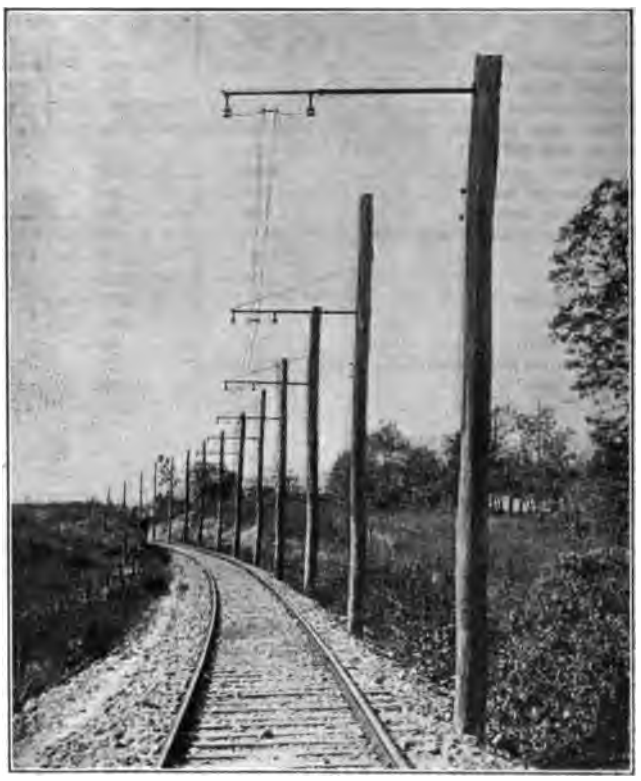
a Profile: rolling country.
b Transportation required: passenger cars to seat 50 passengers and having baggage compartment; or the equivalent of 60 passengers without baggage compartment.
c Frequency of trains: one every hour in each direction.
d Average distance between stops: 3 miles.
e Schedule speed: 33 miles per hour.
f Length of road: 100 miles.
g To operate on existing 600-volt city tracks.

The general data required are approximated in Tables 17 to 22.

127 There will be an additional cost of operation and maintenance with the single-phase system for the items of track and roadway, due to additional weight of cars, car shop expenses in providing greater facilities for shop inspection and repairs, and greater skill in superintendence of equipment. In a number of instances this

ɔeen found to amount to several cents per car mile. A conserva-
ɛstimate would require at least one cent per car mile to be added
hese items.

3 The comparison in Table 22 brings out the fact that even for
itions selected as favorable to the single-phase system, the 600-



15 1200-VOLT DIRECT-CURRENT OVERHEAD-LINE CONSTRUCTION OF THE TSBURG, HARMONY, BUTLER & NEW CASTLE RAILWAY, PITTSBURG, PA.

direct-current system is the more economical considering opera-
maintenance and fixed charges. An examination of the elements
h enter into the first cost and operation of a system will show
ıce that as the density of traffic increases there is a rapid gain
e relative advantage of the direct-current over the single-phase
ˈm.

TABLES RELATING TO TYPICAL INTERURBAN ELECTRIC SERVICE

TABLE 17 GENERAL DATA FOR CARS

	600 v. D. C.	1200 v. D. C.	6600 v. A. C.
Number of cars	15	15	18
Seating capacity, passengers	60	60	60
Distance between stops, miles	3	3	3
Schedule speed, miles per hour	33	33	33
Maximum speed, miles per hour	48	48	48
Weight each car, tons (2000 lb.)	35	36	42
Car miles per day	3000	3000	3000
Miles per car in service per day	300	300	300
Miles per car per day, average[1]	200	200	166
Estimated maintenance per car mile, cents			
a Electrical	0.70	0.77	1.00
b Mechanical	1.00	1.00	1.25
Total car barn expense	1.70	1.77	2.25
Amperes starting car	520	280	75
Amperes running car	174	94	24
Kilowatt hours per car mile at car	2.8	2.88	3.75
Cost each car complete	$10,000	$11,500	$17,000

TABLE 18 SUB-STATIONS

	600 v. D. C.	1200 v. D. C.	6600 v. A. C.
Number of sub-stations	9	4	3
Estimated momentary demand			
Cars starting	1	1	1
Cars running	1	1	0
Peak load, kilowatts	416	448	670
Average load, each sub-station, kilowatts	52	120	270
Size each unit, kilowatts	300	300	300
Number of units	2	2	3
Load factor (machines in service)	0.17	0.40	0.45
Average efficiency	0.76	0.87	0.91
Cost each sub-station complete	$24,000	$26,400	$40,000

[1] On twelve American single-phase interurban roads the average miles per day called for on the published time tables, divided by the number of cars owned, is 138; on four 1200-volt roads which have been operating over a year this number is 237, the larger number of alternating-current cars being required on account of the fact that a greater number are necessarily held in the barn for inspection and maintenance purposes. This explains why, in the table above, 18 alternating-current cars are assumed and 15 direct-current cars.

TABLE 19 FEEDER COPPER REQUIREMENTS

	600 v. D. C.	1200 v. D. C.	6600 v. A. C.
ım momentary demand midway be- sub-stations.			
s starting	1	1	2
s running	0	1	0
s	520	374	150
e between sub-stations	11.8	28	66.6
lent stub-end feed	2.9	7	16.6
required additional to 4/0 trolley	4/0	1/0	none
erhead construction per mile, includ- oth trolley and feeder	$2300	$2100	$1900

ing taken as $400 per mile of track.
mission line taken in each case as $840 per mile of track and assumed to run entire length of way.
r house: No power house is included, but it is assumed that power is purchased at the power bus at one cent per kw-hr. and fed at any convenient point into the transmission line.

TABLE 20 POWER CONSUMPTION

	600 v. D. C.	1200 v. D. C.	6600 v. A.C.
ilowatt-hours per day at cars	8400	8650	11,400
icy, secondary distribution	0.90	0.90	0.94
itions	0.76	0.87	0.96
ission line and power house stepup formers	0.94	0.94	0.94
ned efficiency	0.64	0.74	0.85
it-hours per day at power house	13,100	11,700	13,400

TABLE 21 SUMMARY OF COSTS

First Costs

	600 v. D. C.	1200 v. D. C.	6600 v. A. C.
ission	$ 84,000	$ 84,000	$ 84,000
itions	216,000	106,000	20,000
ary distribution	230,000	210,000	190,000	
e	40,000	40,000	40,000
	150,000	172,500	306,000
al	$720,000	$612,500	$640,000

ANNUAL FIXED CHARGES

DEPRECIATION	Life Years	Annuity 5%	600 v. D. C.	1200 v. D. C.	6600 v. A. C.
Transmission	20	30.34	$ 2,560	$ 2,500	$ 2,500
Sub-stations	20	30.34	6,600	3,200	600
Secondary distribution	15	46.34	10,600	9,700	8,000
Bonding	10	79.50	3,200	3,200	3,200
Cars (A. C.)	12	62.83	.....	.....	19,200
Cars (D. C.)	15	46.34	6,900	8,000	.....
Total Depreciation			$29,700	$26,600	$34,300
INTEREST AND TAXES					
Interest 5%, taxes 1.5% of cost of electrical material			$16,000	$39,800	$41,600
INSURANCE					
1.5% of sub-station and car costs			$ 5,500	$ 4,200	$ 4,900
Total fixed charges			$81,200	$70,600	$80,800

ANNUAL OPERATION AND MAINTENANCE

	600 v. D. C.	1200 v. D. C.	6600 v. A. C.
Transmission	$ 3,500	$ 3,500	$ 3,500
Sub-stations	17,000	7,600	800
Secondary distribution, including bonds	9,000	9,000	10,000
Cars	18,500	19,500	30,100
Power at one cent per kw-hr	47,800	42,700	40,000
Additional cost maintenance of track and roadway, shops and supervision, due to heavier cars and more expert supervision required for the single-phase	.....	.....	10,900
Total	$95,800	$82,300	$104,000

TABLE 22 COMPARISON OF COST OF SYSTEMS

	600 v. D. C.	1200 v. D. C.	6600 v. A. C.
1 First cost	$720,000	$612,500	$640,000
2 Fixed charges	$ 81,200	$ 70,600	$ 80,800
3 Operation and maintenance	95,800	82,300	104,000
4 Annual cost (Item 2 plus Item 3)	$176,000	$152,900	$184,800
Based on 1,095,000 car miles per year, additional annual charge per car mile above the cost for 1200 volts, in cents	2.1	....	2.9

CONCLUSION

29 The saving effected by the 1200-volt direct-current system is narked that a great increase in the adoption of this potential for class of interurban railroading may be anticipated, and on the er hand it will not be surprising if the single-phase interurban :em is entirely discarded in America, unless some marked improve- ıt is made in the art and a more economical equipment made ilable. There is no question regarding the mere movement of ns by any particular system—this may be taken for granted. e study of electrification is really a problem in economic engi- ring and not simply a technical problem.

30 Reliability of operation is of the greatest importance, not y to the public but to the operating company, and in this respect electric motor with its simpler construction, even though the ıeral service is supplied from a central power station, has proved superiority over the steam locomotive. Except in the case of ne extraordinary accident, the power station, sub-stations and nsmission line, in their entirety, are rarely rendered inoperative. e liability to interruption is principally centered in the equipment :he rolling stock, and for this reason the mechanical and electrical ign of the motors, control and equipment devices, should receive eful consideration.

31 The electrical equipment of motor cars and locomotive is osed to a large extent to dirt, water and snow, and not being par- ılarly convenient for inspection, it usually receives less attention n the apparatus in the power station and sub-stations. It is the tom on many roads to give the equipments a regular inspection :e in a thousand or fifteen hundred miles, depending on experience, l to dismantle them for a thorough overhauling once a year. e character of the rolling stock equipment is a factor of far more portance to the reliability of the service than is often appreciated.

32 The steam locomotive has been brought to its present state of velopment through many years of experience. It is an exponent the highest type of mechanical design, and notwithstanding its ıitations, is remarkably efficient as a source of power. During : past twenty years the power of the steam locomotive has been ıctically doubled, but the demand today is for still greater power.

33 The multiple-unit idea, to which electric service is so well ıpted, was utilized in the design of the Mallet type of steam loco- ıtive where the driving engines of two practically separate

locomotives are supplied with steam from a single boiler. Mallet locomotives have been built having a weight of 441,000 lb. on the drivers, the boiler having over 5800 sq. ft. of heating surface and a grate area of 100 sq. ft. To fire properly a locomotive of this capacity is difficult, and unlike the electric locomotive, its effectiveness depends on the steam from its own particular boiler.

134 With existing road clearances the steam locomotive unit, controlled by a single engineer, seems to have reached nearly the limit of power. The power of a steam locomotive being limited by the capacity of its boiler, an increase in speed can be secured only by a proportional reduction in tractive force. The electric locomotive, on the other hand, is supplied with practically unlimited power from an independent power station, and can maintain a speed and tractive force that would be impracticable with a steam locomotive. The application of electric locomotives to passenger and freight service will result in faster schedules with equal or even heavier trains than are at present handled by steam locomotives.

135 Since the electric locomotive is equipped with a number of independent motor units, controlled by one engineer from a single master controller, it makes no difference, considering the complete locomotive as a machine, whether it be built as a single unit, or as two or three units having the same total weight on the drivers. For convenience in operation and repairs, it is probable that a single electric locomotive unit will be limited to a weight between 200,000 and 300,000 lb. on the drivers, even when built for the heaviest service. There are electric locomotives now under consideration which as single units will exert a maximum tractive effort of 90,000 lb., and which will be capable of maintaining a tractive effort of 35,000 lb. at a speed of 30 miles per hour.

136 Many of the terminal and tunnel electrifications have been brought about from the desire to do away with the danger and nuisance caused by smoke and gas. The elimination of smoke has also an economic aspect in the electrification of terminal stations, in permitting material improvement in the character and value of railway buildings. The Quai d'Orsay terminal of the Paris-Orleans Railway in Paris, which has been in operation since May 1900, was the first instance where a steam railway profited by this feature of electrification.

137 The enhanced value of railway buildings is seen to a marked degree when terminals are electrified in large cities in which land values are high. The fact that electric operation will permit platforms

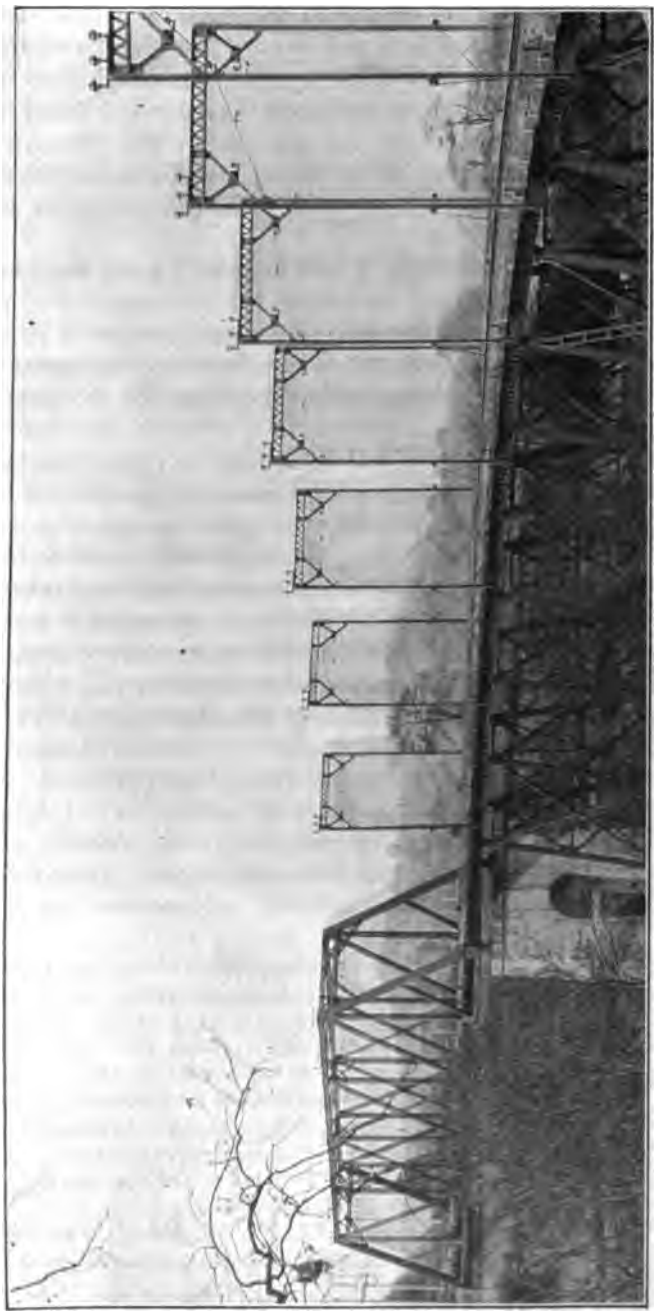


FIG. 16 1200-VOLT OVERHEAD LINE CONSTRUCTION ON STEEL TRESTLE, PITTSBURG, HARMONY, BUTLER & NEW CASTLE RAILWAY, PITTSBURG, PA.

on two or more levels adds greatly to the capacity of the station, or conversely, decreases the land area required for given traffic facilities. In the case of the New York Central terminal in New York City, there will be two levels of platforms, the entire suburban facilities being placed below those of the main line. The Pennsylvania terminal in New York is another instance of station design affording facilities for handling traffic that would be impossible under steam operation.

138 The electric locomotive is well adapted for the handling of trains where the character of the service will not permit the operation of individually equipped cars. Where the service is self-contained, individually equipped motor cars, operated in trains with multiple-unit control, are recognized as providing for the most efficient handling of traffic.

139 Economy in operation will be secured by proportioning the number of cars in a train to the traffic required during different hours of the day. The patronage on which the gross receipts depend will be much encouraged by providing a service with short intervals between trains. In the study of any scheme of transportation, due regard should be given not only to economical operation but also to the method of handling which will insure the maximum gross receipts.

140 The author desires to express his thanks to Mr. C. E. Eveleth for his assistance in the preparation of this paper.

No. 1293*e*

THE ELECTRIFICATION OF TRUNK LINES

By L. R. Pomeroy, New York

Member of the Society

1 It is assumed from a physical and mechanical viewpoint, that ric traction can meet all the demands and requirements of rail- service. Therefore, whether electricity will replace steam ion or not is entirely a commercial problem.

THE COMMON DENOMINATOR = COMMERCIAL CONSIDERATIONS[1]

2 It may be stated at the outset that whatever system of elec- ation is adopted, a very large outlay has to be faced and no case lectrification can be made out unless an increase in net receipts e secured more than sufficient to pay interest on the extra capital lved. This increase may be brought about either by decreasing vorking expenses for the same service, by so modifying the service bring in a greater revenue, or by a combination of these.

3 However, there is hardly a steam road in existence today which not have divisions or sections, where distinctly local traffic be handled more profitably by light, comparatively frequent ic service, than as now, with heavy steam trains. Steam and ic service can be operated over the same tracks without

[1] Commenting on the problem of electrification of the Central Pacific over erras, Mr. Kruttschnitt says: "Eastern critics may be inclined to the n that we are dallying with this matter. We have found that it pays o make haste slowly with regard to innovations. Electrification for tain traffic does not carry the same appeal that it did two years ago. urning locomotives are solving the problem very satisfactorily. Each t compound locomotive, having a horsepower in excess of 3,000, hauls at a load as two of former types, burning 10 per cent less fuel and con- g 50 per cent less water."—*Wall Street Journal.*

sented at the meeting of The American Society of Mechanical Engi- s with The Institution of Mechanical Engineers, London, England, 1910.

detriment or embarrassment to either. In so doing each kind of service would be appropriately handled in a manner best suited to the conditions of each.

144 The fundamental principle, based on the present state of the art, seems to be that if you cannot accomplish something by means of electricity that is now impossible by steam traction, there is nothing to justify the change; the mere substitution of one kind of power for another, merely to obtain the same result, is not commercially warranted.

145 There are certain inherent advantages in electrical operation that have shown up very well, because the increase in business has absorbed the increased interest account, but these cases hardly apply to trunk line conditions, as the law of induced travel has no bearing on freight train operation, the principal business of trunk line roads.

146 In heavy work the limiting feature of the steam locomotive is the boiler, and the maximum adhesion can be utilized only at low speeds. For example, a 2–8–0 locomotive with 180,000 lb. on the drivers, has a tractive force, at 10 miles per hour, of about 40,000 lb. or 4.5 to 1. At 30 miles per hour the tractive force becomes 13,250 lb. or 30.2 to 1. As tractive force governs the tonnage hauled, the ability of the electric locomotive to utilize almost indefinitely power proportional to the maximum adhesion and produce a drawbar pull entirely independent of the critical speed of a steam locomotive, as limited by the boiler, is a marked feature.

147 In heavy grade work the ability to increase the speed shows up favorably to the electric locomotive as enlarging the capacity of a given section, but here also the business has to be sufficient to absorb the increase in fixed charges.

148 With steam locomotives a coal consumption, when running, of 4 to 5 lb. per i.h.p-hr. really means 6 or 7 lb. at the rail, when the losses due to firing up, laying by in yards and sidings, blowing off at the pops, and consumption of the air pumps, are taken into account. Whereas, under electric operation, with an efficiency of 65 to 70 per cent between the power house and the rail, a coal consumption of 4 lb. per kilowatt hour at the rail can be counted on.

149 The writer is informed that the Metropolitan Street Railway station (1903) with a 40 per cent load factor, produced power, at the switchboard, at the rate of 4.7 mills per kilowatt hour (or 3.5 mills per horsepower hour), and with a load factor of 55 per cent which prevails in the winter time, the cost is at the rate of 4.43 and 3.3

ills respectively. These costs cover all expenses and repairs except ed charges. The coal consumption is 2.9 lb. per kilowatt and 2.16 . per horsepower hour.

150 L. B. Stillwell is authority for the statement that the Interrough is producing power at the rate of 2.6 lb. of coal per kilowatt . or 3 lb. at the drawbar.

151 Another authority gives the following figures for the elevated ads for cost of power, $0.005 per kilowatt hour at the switchboard, .0066 at the third rail shoes, or $0.0089 at the rims of the drivers. hese figures are exceptional and hard to duplicate and as the fixed arges are not included, the writer would consider 1½ cents per kiloatt hour at the rail a conservative figure, and will use this cost the following computations.

RELATIVE COST OF COAL FOR STEAM AND ELECTRIC OPERATION

152 It may be fair to assume that where average coal is used, we an count on about $2.25 per ton for locomotive coal on the tender, hile a much cheaper grade can be used in the power house, costing, ith modern coal handling facilities, about $1.50 per ton. At this te the relative difference in the cost of coal at the rail would be presented by the following figures:

lectric power station	$\frac{2.5 \text{ lb.}}{50\% \text{ eff.}} \times \$1.50$	$7.50
eam locomotive	$7 \times \$2.25$	$15.75

50 per cent in favor of electricity. The following results of the Jersey Tunnel operation are pertinent: Under electric operation ne ton of coal at $2.10 yields 2.29 ton miles at 22½ miles per hour, hile with steam, one ton of coal at $3.84 yields 2.21 ton miles at 7¼ miles per hour. The difference amounting to 55 per cent is in vor of the electric operation, thus:

$$\left[1 - \frac{2.10}{3.84}\right] \times \frac{22.5}{2.29} \div \frac{17.75}{2.21} = \left[1 - \frac{2.10}{3.84}\right] \times \frac{22.5 \times 2.21}{2.29 \times 17.75} = 55\%$$

153 On mountain grades or in heavy freight service, where the oiler of the freight locomotive is forced to the limit, and the boilers re designed for this particular purpose, the showing is still more vorable to the electric side. Especially is this true when the eam locomotive is detained on side tracks for as long a period as takes to make the run, which is very frequently the case, since under

these conditions the cost for fuel becomes a larger proportion of the total operating expense. A 2-8-0 locomotive with 50 sq. ft. of grate surface burns 300 lb. of coal per hour while lying on side track. Reports from Mallet locomotives indicate that from 600 to 800 lb. are burned per hour under the same conditions.

154 The cost of a unit of power with the steam locomotive becomes relatively higher under maximum than minimum boiler demands, while with electricity the cost per unit is at a uniform rate, whether working under extreme or light power demands. For example:

155 *Case 1.* A consolidation (2-8-0) type locomotive with 180,000 lb. on 57 in. drivers, 50 sq. ft. of grate surface, working under maximum conditions on a 1½ per cent grade, would burn 150 lb. of coal per sq. ft. of grate surface per hour and evaporate from 12 to 15 lb. of water per sq. ft. of heating surface per hour. Under these conditions the cost per 1000 ton miles would figure out as follows:

$$\frac{F \times \text{price per ton} \times R \times 1000}{2000 \times \text{m.p.h.} \times E \times TF} = \text{Cost per 1,000 ton miles}$$

where F = coal per hour (150 lb. × 50 sq. ft. of grate surface).
R = resistance to be overcome [(grade per cent × 20) plus 6].
E = 80 per cent efficiency to cover losses such as cleaning fires, idle time while under steam, cylinder condensation, air pump consumption, etc.
TF = tractive force, in this case 180,000 lb. on drivers ÷ 4.5 = 40,000 lb.

Substituting these values, the formula becomes

$$\frac{7{,}500 \text{ lb.} \times \$2.85 \times 36 \times 1{,}000}{2{,}000 \times 10 \times 80\% \times 40{,}000} = \$1.20$$

If the same service is handled by electric locomotives the cost on a similar basis becomes

$$\frac{R \times (\text{watt-hr. per ton mile}) \times 1{,}000 \text{ tons} \times \text{price per kw. at the rail}}{1{,}000 \text{ watts}}$$

$$= \frac{36 \times 2 \times 1{,}000 \times \$0.01\frac{1}{2}}{1{,}000} = \$0.90$$

156 If locomotive coal is taken at $1.70 per ton (the price in Eastern Pennsylvania for low grade soft coal), the cost for coal for locomotives under the foregoing conditions would be:

(*a*) Steam, $\frac{\$1.20 \times 1.70}{2.85} = \$0.716$

(b) Electric current reduced to 1c. per kw. hour at the rail:

$$\frac{0.90 \times 1\text{c.}}{1\frac{1}{4}\text{c}} = \$0.72$$

157 *Case 8.* An express passenger locomotive of the Atlantic (4-4-2) type, with the following data: Cylinders 21 by 26 in., boiler pressure 200 lb. per sq. in., weight on drivers 102,000 lb., heating surface 2,821 sq. ft., grate surface 50 sq. ft., rate of combustion 150 lb. per sq. ft. of grate surface per hour, speed 70 miles per hour. Figuring as in Case 1

$$\frac{7{,}500 \times 2.85 \times 20 \times 1{,}000}{2{,}000 \times 70 \times 80\% \times 5.350} = \$0.71$$

Under electric conditions we have

$$\frac{20 \times 2 \times \$0.01\frac{1}{4} \times 1{,}000 \text{ tons}}{1{,}000 \text{ watts}} = \$0.50$$

or 28½ per cent less.

158 If coal is taken at $1.70 per ton, as in Case 1, the cost is reduced from $0.71 to $0.42, making the difference slightly in favor of steam.

159 These figures apply only to the conditions named, and average conditions on an undulating profile, when coasting is occasionally possible. With the benefits of momentum grades, also, the figures would be relatively less, but the electric locomotive would respond and benefit accordingly, so that the percentages would be approximately the same.

160 When steam locomotives are loaded to their capacity, as is generally the case where tonnage rating is practiced, the rate of combustion of 150 lb. of coal per square foot of grate surface per hour, will still hold good and remain constant, the tons hauled being the variable, responding to or being modified by the speed or physical conditions of the road.

SAVINGS CLAIMED FOR ELECTRIFICATION

161 In view of the foregoing the following extract from an article by Mr. C. L. De Muralt will be of interest. The figures are from the annual report of 1903 of the roads named.

COST OF OPERATING TRUNK LINES

	P. R. R.	N. Y.
Fuel for locomotives	$6,000,135	$4,6
Water " "	335,286	2
Other supplies for locomotives	382,548	3
Wages: Enginemen and roundhouse men	5,716,848	4,9
Other trainmen	4,442,127	2,9
Switchmen, flagmen and watchmen	3,900,427	2,5
Other expenses of conducting transportation	14,540,542	11,0
Repairs to locomotives	4,412,983	3,0
" other equipment	10,674,726	5,0
" roadbed	8,542,935	6,1
" structures	4,122,018	2,4
General expenses	1,858,319	1,7
	$64,928,894	$46,9

162 Mr. De Muralt then applies the figures found during the c of his investigation, which would lead to the following reducti electricity was adopted as a motive power.

	P. R. R.	N.
Fuel 10 per cent	$600,013	$
Water saved entirely	335,286	
Other supplies 50 per cent.	191,274	
Wages, enginemen, etc., 25 per cent	1,429,212	1,
Repairs to locomotives	2,206,492	1,
Total amount saved	$4,762,277	$3,

163 The saving in water alone capitalized at 5 per cent $6,750,000 for the former and nearly $6,000,000 for the latte As large as these alleged savings are, yet they would not amou more than 2½ to 3 per cent on the necessary increase in capi electrify the roads on which the foregoing savings apply.

164 While the first cost for power stations and electric equi represents a large outlay, yet such items as the cost for rep locomotives and shops, expensive hostlering at terminals, c and water stations, and the incidental labor charge and repairs t will, in the aggregate, be materially reduced. The compa saving in repairs will be indicated by the following figures:

Repairs	Steam	Electric
Boiler	20%	0%
Running gear	20%	20%
Machinery	30%	15%
Lagging and painting	12%	5%
Smoke box	5%	0
Tender	13%	0
	100%	40%

OTHER COMPARISONS BETWEEN STEAM AND ELECTRIC LOCOMOTIVES

165 It is further claimed that, with electric operation, greater mileage is possible with the electric locomotive and that fewer units are necessary to perform the same service. Great stress is laid on the fact that the ordinary freight locomotive makes only 3,000 miles per month, or 100 miles per day, against which is put forward

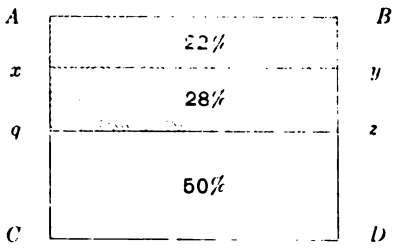


FIG. 17 DIAGRAM SHOWING DIVISIONS OF LOCOMOTIVE WORKING DAY

the ability of the electric locomotive to perform practically continuous service, suggesting the propriety of comparing electric and steam operation on the basis of ton miles per annum each is able to make and also the relative weight on driving wheels and not their total weight.

166 The operating efficiency of a steam locomotive in freight service is so low, averaging about 3,000 miles per month, that it is generally thought due to limitations, *per se*, in the locomotive, whereas it is mainly due to operating and traffic conditions, which limitations would apply with equal force to the electric locomotives, so that barring some increase in speed, the electric locomotive can make no greater mileage than its steam competitor in equivalent service, consequently its splendid ability to perform almost continuous service cannot be realized in practice for reasons aforesaid.

167 Let the rectangle $ABCD$ represent a day of 24 hours; the shaded area $ABxy$ that portion of the time for which the mechanical department is responsible 22 per cent; the area $xyqz$, the average

time the locomotive is performing useful work = 28 per cent—i. e., actually pulling trains, 3000 miles per month, 100 miles per day; while the portion of the diagram bounded by $qzCD$, is the period or balance of the time that the locomotive is under steam, with crew, and ready to go, and represents the time at terminal yards, side tracks and awaiting orders, etc. = 50 per cent.

168 It is just here that our electrical friends make the great mistake of claiming "greater capacity" for the electric locomotive over its steam equivalent. It is conceded that under electric conditions the area $ABxy$ may be reduced as much as one-half and perhaps, owing to greater speed, the area $xyqz$ may be increased, but the "lost motion" period due to traffic and operating causes will be relatively the same for both. The percentages are from an actual three months' test on a trunk line reported in1904 in the proceedings of the American Railway Master Mechanics' Association by the committee on time service of locomotives.

169 The only cases where electric operation is commercially justified is in congested local passenger situations where the conditions closely approach those of a "moving sidewalk" and the records show that these cases have been profitable only when a large increase in business has been realized.

170 A modern Atlantic (4–4–2) type locomotive weighs, including tender, 321,620 lb. with a maximum tractive force of 23,500 lb. The ratio of total weight to tractive power is 133 to 1. The New York Central electric locomotive, with a total weight of 192,000 lb. and a tractive effort of 27,500 lb. has a ratio of 7 to 1. The comparison is still more favorable for electric freight locomotives where the entire weight is on the driving wheels.

POWER STATION CAPACITY

171 The impression is quite prevalent that if 100 steam locomotives are required to operate a certain division, a power station capacity equivalent to 100 locomotives would be necessary, if operated electrically, whereas the generator capacity, barring the installation of spare units, would be of such size as to meet the average load. This average can be determined by laying down a train sheet, from which the load at any hour in the day can be seen and the peaks located.

172 For ordinary computations the number of trains to provide for is, approximately:

$$\frac{\text{total train miles per hour}}{\text{mean speed}}$$

173 This formula is the result of cancellation from the following:

(*a*) h. p. days + Aggregate h. p.

That is:

$$(b)\quad \frac{5{,}280 \times (\text{distance miles}) \times (\text{no. trains}) \times (\text{tons}) \times R}{47{,}520{,}000 \text{ ft. lb. in 1 day}} + \frac{\text{tons} \times R \times \text{m.p.h.}}{375}$$

R = resistance due to gravity, + resistance due to speed, + curve resistance. Transposing and cancelling:

$$(c)\quad \frac{\text{distance miles} \times \text{no. trains}}{24 \times \text{m.p.h.}}$$

For illustration take a typical case: Distance 183 miles.

LOAD		AVERAGE SPEED	
37 freight trains	at 15 m.p.h.	37 × 15 m.p.h. =	555
22 expresses	at 50 m.p.h.	22 × 50 m.p.h. =	1,100
21 locals	at 30 m.p.h.	21 × 30 m.p.h. =	630
80 trains total.		80	2,285

2285 + 80 = 28 average m.p.h.

$$\frac{80 \text{ trains} \times 183 \text{ miles}}{24 \text{ hr.} \times 28 \text{ m.p.h.}} = 22 \text{ trains}$$

174 For more accurate work a train sheet should be made either with miles as ordinates and time as abscissae, or one with trains as ordinates on a time (abscissa) base.

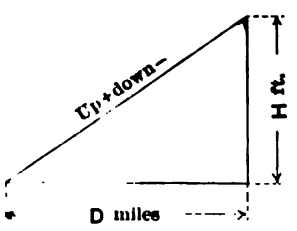
175 Relative to R (*i.e.*, resistance for gravity), divide the profile into sections, one for each change in grade, plus or minus as the case may be:

$\frac{H}{D \times 52.8}$ = per cent grade

Each 1% grade = 20 lb. = R

R for curves 0.56 lb. per deg.

R for level sections = $2 + \frac{\text{m.p.h.}}{4}$



176 Consider the example of a road or division 100 miles long on which a given train requires 2,000 h.p. to keep it in motion. If 20

cars take a maximum of 100 h.p. each, the electrical conductors and distributing apparatus will never be required to deliver more than 100 h.p. at any one point. If on the other hand, the entire traffic of the line must be concentrated in a single train, the electrical conductors and distributing apparatus must deliver the full 2,000 h.p. at each and every point. In other words, with the concentrated load, the capacity of the distributing apparatus at each and every point must be 20 times as great as the capacity when 20 cars are used to give the same total load. Electric traction has proved its superiority for distributing loads, but concentrated loads are still handled almost exclusively by steam locomotives.

SOME ADVANTAGES OF ELECTRIC LOCOMOTIVES

177 In the annual report of the P. R. R. (1903) the president states: "That the congested condition of your system has brought about a large increase in the ton mile cost, which for 1903 was 25 per cent greater than for 1899. In order to prevent the increase in ton mile cost, it is necessary to move freight trains faster in places where traffic is dense, and for such purposes the electric locomotive is most efficient."

178 With steam locomotives the most economical average speed, for freight service, is 12 to 15 miles per hour, where there is ample track space for the free movement of trains. With a dense traffic this free movement can only be obtained by a higher speed and if the large train tonnage be maintained, more horsepower is required of the engine and boiler. It is difficult to increase the size of steam freight locomotives without resorting to the Mallet compound articulated type, and here we have the equivalent of two locomotives in one machine.

179 With the electric locomotive it is possible to develop a much greater horsepower and a large percentage of overload at the time when needed and do it more economically than with steam. The New York Central electric locomotive has a maximum peak horsepower of 3,000, which is 25 per cent above normal. This maximum is about double the power which can be obtained from the New York Central standard Atlantic (4–4–2) type locomotive. Similar proportions can be obtained for electric freight locomotives and their size and power are not limited by boiler capacity. If the steam locomotive is capable of developing 30,000 T. F. at the drawbar at 12 m.p.h. or

$$\frac{30{,}000 \times 12 \text{ m.p.h.}}{375} = 960 \text{ h.p.}$$

ıd it is required to increase the speed of the train to 20 m.p.h. and aintain the same tonnage, then 1,600 h. p. will be required, which eans the employment of a much larger locomotive or double ading.

180 The advantage of the overload capacity on short mountain ades or for strategic peaks is one of the strong points in favor of the ectric machine and would make electric operation applicable to ecial cases rather than a universal substitute, in the broad light commercial considerations.

GENERAL CONCLUSIONS

181 Our conclusion, from this survey of the situation, is that the ıpid development of suburban passenger traction by electricity ill require large power houses at large cities and these can gradually e made sufficient for working the line on further stretches in each rection, handling congested terminals, or used where commercially acticable, until it may be desirable to electrify the entire division.

182 Electric operation as compared with steam shows to greatest lvantage in urban and suburban passenger service. Here, if multi-e unit trains are employed, so that a considerable fraction of the tal weight is carried on the driving wheels, thus permitting a high te of acceleration to be used, a schedule speed quite impracticable steam operation can be maintained. Moreover, a more frequent rvice can be given without a proportional increase in expense, whilst times of light traffic small trains can be run, the energy consump-ɔn per train in such service being almost in proportion to the num-r of coaches. The law of induced travel, however, applies to urban ıd suburban passenger service, but does not hold for trunk lines and pecially freight service.

TO DETERMINE WHETHER IMPROVEMENTS ARE JUSTIFIABLE

183 Under trunk line conditions the only thing that interests ilway managers is the traffic available at the present, relatively eaking; the future is too indefinite to be capitalized to any great gree in advance. It is more in the line of insurance companies to apitalize expectations."

184 In grade revision the authorization for expenditure is based ı the saving in train miles capitalized. The following is a concrete se from a Western road, or rather the summation of the engineer's

report as to just what the proposed rearrangement would amount to. The rate of 50 cents per train mile is to cover those items of cost directly affected by the change.

$$\left[\begin{array}{c}\text{No. of}\\ \text{trains per}\\ \text{day—7}\end{array}\right] \times \left[1 - \frac{\text{1,350 tons present conditions}}{\text{1,600 tons proposed}}\right] \times \left[\begin{array}{c}\text{Div. of}\\ 225\\ \text{Miles}\end{array}\right] \times 50\text{c.} \times \left[\begin{array}{c}365\\ \text{days}\end{array}\right] = \$45{,}990$$

185 Under the circumstances it will be seen that the value of 1 per cent reduction in train mileage amounts to $1.95 per mile per train per annum. The total amount capitalized at 5 per cent equals $919,800. In some such manner the steam railroad manager arranges the proposition of the electric scheme and decides accordingly.

SOME EXAMPLES

186 In a paper before the American Society of Civil Engineers by W. J. Wilgus, some interesting data concerning New York Central operation were given:

Cost of coal per 2,000 lb. anthracite steam locomotive, terminal service	$4.
" " bituminous coal, road service	1.
" " " " power station	1.
Water per 1,000 gal. :—	
Power station	12.5 c
Road service	5

187 The cost of current, when power station designed load is attained, is 2.6 cents per kilowatt hour delivered at contact shoes. This includes all operating and maintenance costs, interest on the electrical investment required to produce and deliver current, depreciation, taxes, insurance and transmission losses. The following table summarizes the data:

Items	Operating Costs	Fixed Charges	Total
Power station	0.58 cts.	0.44 cts.	1.02 cts.
Transmission losses	0.19 cts	0.15 cts.	0.34 cts.
Distribution systems			
Sub-stations	0.32 cts.	0.92 cts.	1.24 cts.
Totals	1.09 cts.	1.51 cts.	2.60 cts.

) In a discussion by G. R. Henderson[1] are given road ser- osts per 1,000 car ton miles:

	Steam	Electric
ies.....	$2.03	$1.37
.....	0.28	0.31
st, depreciation, and repairs to comotive.....	0.46	0.34
	$2.77	$2.02

) The item electric supplies is composed of operating expenses ixed charges and may be analyzed thus:

w-hr. at $0.0109, $0.58 operation
w-hr. " 0.0151, 0.79 fixed charges
w-hr. " 0.026, 1.37

$$[\text{Fixed charges} = \left(\frac{0.79}{1.37}\right) = 57 \text{ per cent of operating expenses}]$$

brackets are ours. The difference in cost between steam and ic traction in road service is $2.77 − $2.02 = $0.75 per 1,000 car iles.

) The fixed charges on the power plant and the transmission sys- re $0.79 per 1,000 car ton miles, or about the same as the saving, at if the train movement were but one-half the assumed amount aging 6,000 h.p. at the rails, or 6,000 kw. at the station) the for electric service would be slightly higher than for steam, or as against $2.77 per 1,000 car ton miles.

l The Manhattan Elevated, with about 38 miles of road, was ified at an expense of $17,000,000. The operating ratio, under ic conditions, has been reduced from 61 to 46 per cent of receipts. The net result after taking care of the increased al, etc., shows 15 per cent profit, but it is a significant fact that ncrease in business was 46 per cent (carrying about 250,000,000 le per annum, 690,000 per day average, or 28,800 per hour).

2 There has just been reported the four years' electric operating ts of the Mersey tunnel road connecting Liverpool and Birken- . The net profit, allowing interest, etc., on the increased capital o electrification, amounted to 15 per cent, but it took an increase affic of 55 per cent to make this operating result possible. Ton increased from 43 to 67 million, or 55 per cent. Total expenses, n include operating expenses and interest on electric capital not depreciation) equal $0.586 per ton mile. Interest equals 6 per ton mile, or 22 per cent of operating expenses.

3 President Harahan of the Illinois Central reports the results

[1] Trans. A.S.C.E., vol. 61, p. 102.

of the investigation that has been made relative to the propos electrification in the following words:

194 "Our suburban traffic is the only service which would in a degree be adapted to electric operation, but even in this particul service it can be readily shown to be unjustifiable at the present tim I submit below a statement of the results which are estimated accrue if the entire suburban service were electrified, compared w the present steam operation:

"Results of Operation of Suburban Business at Chicago for Fiscal Y ending June 30, 1909:

Gross earnings		$1,08
Operating expenses (82.9%) plus taxes		94
Net revenue		$13
"Estimated Results Under Electrification:		
Gross earnings		$1,08
Operating expenses (66%)	$697,254	
Taxes	74,427	
		$77
Net revenue (electric operation)		$30
Net revenue (steam operation)		10
Increase		$17
Estimated cost of electrification		$3,0
Interest and depreciation 10%		$30
Saving in operation under electrification		17
Deficit		$28

195 "Our suburban traffic is not sufficiently dense to warran expense necessary to electrify these lines, and it is evident from foregoing figures that even under electrification there would not b increase in traffic sufficiently large to offset the annual loss operation. It simply proves that under present conditions of co electrification of steam railways, where it means a replacem a plant already installed, and serving the purpose, it is not justif to electrify either in whole or in part your Chicago terminals at time."

196 The suburban district of the Illinois Central covers a 50 miles of road and carries in round numbers 15,000,000 subu passengers per annum, or an average of 41,150 per day, or 1,70 haur. An increase of 100 per cent in earnings would not enabl road to break even.

197 The Railway Age Gazette, in commenting editorially on Mr. Harahan's statement, says:

198 "It may be accepted as conclusively demonstrated that the New York Central and the New Haven roads are moving trains by electricity more economically than they moved them by steam in their suburban district. To enable this to be brought about, however, extremely heavy capital costs had to be assumed and the charges on these capital costs make the entire operating cost, including overhead charge, far higher than it used to be in the days of steam operation.

199 "For example, a standard express train of eight cars on the New Haven road pulls out of Grand Central station headed by two half-unit electric locomotives, each of which cost very nearly $40,000. The capital cost of the motive power of this train is in excess of $75,000 [the interest and depreciation amounting to $20 per day]—the brackets are ours. The cost of motive power at the head of a similar New York Central passenger train operated by electricity is about one-half this sum. Moreover, it will be recalled that Mr. Wilgus estimated that the direct costs of electrical equipment represented only one-fourth of the total charges attendant upon electricity. The cost of making everything ready and safe for this kind of operation is far greater than the highest estimates are apt to contemplate."

200 From a report of the Electrical Commission of the State of Massachusetts the following extracts are taken (letter of C. S. Mellen, president of the New Haven road):

201 "We believe we are warranted in saying that our electric installation is a success from the standpoint of handling the business in question efficiently and with reasonable satisfaction, and we believe we have arrived at the point where we can truthfully say that the interruptions to our service are no greater, nor more frequent than was the case when steam was in use. But we are not prepared to state that there is any economy in the substitution of electrical traction for steam; on the contrary, we believe the expense is very much greater."

202 The Boston & Albany Railroad Company reports the result of their study and estimates the requirements as follows: A power station of 6000 kw. will be necessary, with storage batteries to handle the peak load. The total cost of the installation is estimated at $4,000,000, and the interest, taxes, and depreciation at 9 per cent, or about $400,000 per annum. A stock argument for electric operation is the saving to be made in operating expenses, but concerning this the following statement is made:

203 "Some slight economies would accrue in the transportation

expenses under this operation, which would be substantially absorbed by the additional expenses to be incurred for the maintenance of the additional apparatus installed, and the net economies would be so small as to be inappreciable in the consideration."

204 Another stock argument of the advocates of electric locomotives is the growth of traffic which is supposed to result from electric operation. This argument is met as follows in the report:

205 "Considering now the possibilities of increasing the traffic, the statistics of the B. & A. R. R. show substantially the following numbers of passengers handled in the above territory per annum:

1891	4,552,918	1899	3,807,304
1894	4,799,578	1907	4,435,901

206 "The absence of any material increase in traffic is probably due to the fact that the circuit is occupied as a high class residential district not susceptible of rapid subdivision of property, and more particularly to the fact that suburban lines are being rapidly extended into all such outlying districts and afford a more advantageous means of collecting and distributing local travel through the commercial and residential districts than could possibly be afforded by a railroad constructed and operated upon private right of way and devoted largely to long haul operations."

EXAMPLE TO ILLUSTRATE A CONCRETE CASE

207 The following illustration representing a concrete case is selected because of its elementary character, more especially as the case is so simple that all the variables affecting the comparison are eliminated and the amount of coal to perform the operation is directly known:

Conditions: trailing load 1,600 tons; average grade, 1.3 per cent; distance, 8 miles; speed, 15 miles per hr. for electric and 14 miles per hr. for steam locomotive.

(*a*) Electric

1,600 net tons
190 locomotives (2) tons
1,790 gross tons

R = 1.3% grade × 20 = 26 lb.
5° curves 3 lb.
Level 6 lb.

$$\frac{\text{gross tons} \times R \times \text{distance}}{500} = \text{kw-hr. at the rail}$$

Substituting values:

$$\frac{1{,}790 \times 35 \times 8}{500} = 1{,}000 \text{ kw-hr. (at rail)}$$

uivalent kilowatt load at power house =

$$\frac{\text{tons} \times R \times \text{m.p.h.}}{500 \times \text{efficiency } \%}$$

ıere the efficiency between the rail and generators equals 65%, substitut-; as before:

$$\frac{1{,}790 \times 35 \times 15}{500 \times 65\%} = 2{,}900 \text{ kw.}$$

For this particular case current can be purchased from an adjacent power use at the very low rate of one cent per kw-hr. at the rail.
At this rate the power cost per trip will be 1,000 kw. at one cent =$10
b) Under steam conditions we have the same as before, 1,600 net tons + ight of two locomotives, 300, or 1,900 gross tons.
The coal consumption for this particular run is 6,000 lb.
The price per ton to equal the electric cost for power, is:

$$\frac{6{,}000 \text{ lb.} \times \text{price per ton}}{2{,}000} = \$10$$

ansposing:

$$\frac{2{,}000 \times 10}{6{,}000} = \$3.33$$

But as coal for this particular case costs the road $1.70 per ton, the relative ıt, coal against power, is

$$\frac{6{,}000 \times \$1.70}{2{,}000} = \$5.10$$

There is a difference in ton mile hours, in favor of the electric locomotive, e to speed and reduced gross tonnage, as follows:

a Electric $\frac{1{,}790 \times 8 \times 8}{15}$ = 7,640 gross ton mile hours

b Steam $\frac{1{,}900 \times 8 \times 8}{14}$ = 8,690 gross ton mile hours

To make the comparison correct the coal consumption of the steam locoıtive should be proportioned on the ton mile hours produced, and the cost coal then becomes:

$$\frac{\$5.10 \times 8{,}690}{7{,}640} = \$5.80$$

Adding to the foregoing the other operating costs, the relative expense becomes

(*a*) *Electric.* Power	$10.00
Lubrication, supplies, repairs, crew at $0.1158 per 1,000 ton miles, or $\frac{0.1158 \times 1{,}790 \times 8}{1{,}000}$ =	1.66
Interest and depreciation, taxes, insurance, etc., at 10%	1.46
	$13.12

(*b*) *Steam.* Coal as above $1.18

Lubrication, supplies, water, repairs, enginemen at $0.25 per 1,000 ton miles,

$$\frac{\$0.25 \times 1{,}900 \times 8 \text{ miles}}{1{,}000} = \ldots\ldots\ldots\ldots \quad 1.90$$

Interest and depreciation at 10% (2 locomotives)

$$\frac{\$34{,}000 \times 10\% \times 8}{365 \times 24 \times 14} = \ldots\ldots\ldots\ldots \quad 0.22$$

$3.30

Cost per trip in favor of steam, $3.30, or 25% less

208 The idea is all too prevalent with the public, and even with some of the bodies that have been given legal power of supervision over railway companies, that any expenditure which can be forced upon the railway companies is just so much gain for the public. Never was there a more absolute fallacy. In the long run, the cost of every bit of railway improvement must be paid for by those who buy tickets and ship freight. Economy in the administration of our railways is just as important in the interest of the general public as if the railways were actually under government ownership.

No. 1293*f*

'HE ELECTRIFICATION OF RAILWAYS

I IMPERATIVE NEED FOR THE SELECTION OF A SYSTEM FOR UNIVERSAL USE

By George Westinghouse, Pittsburg, Pa.
President of the Society

an illustration of the wonders of the laws of nature, few inventions :coveries with which we are familiar can excel the static transformer : electrical energy of alternating currents of high voltage into the ılent energy at a lower voltage.

have discovered how to make an inert mass of metal capable of forming alternating currents of 100,000 *volts into currents of any red lower voltage with a loss of only a trifle of the energy so trans- d, would have been to achieve enduring fame. The facts divide onor among a few, the beneficiaries will be tens of millions.*

In less than twenty-five years a new industrial and economic ion has been created by the development of apparatus to gen- , distribute and utilize electricity. Not less than two thousand n dollars have been invested in plants to manufacture apparatus, wer houses to generate electricity, in lines of copper wire to mit this mysterious energy, in construction of railways and their ment, and in the manufacture of products unknown before the ıt of electricity.

Large sums have already been spent in the electrification of ons of standard steam railways in England, continental Europe America, and there is now available a fund of information of mable value to guide those charged with the selection of an ical system for railway operations.

The president of our brother Institution of Mechanical Engi- Mr. Aspinall, in his presidential address delivered April 23, placed the railway world under deep obligation for most valu- nformation upon the electrical equipment and operation of of the Lancashire & Yorkshire Railway, of which he is the

sented at the meeting of The American Society of Mechanical EERS with The Institution of Mechanical Engineers, London, nd, July 1910.

worthy and skilful general manager. His observations on the effects of low center of gravity and heavy inflexible motor trucks upon the permanent way are especially valuable in that they direct attention to costs which at first were not considered with sufficient care.

212 Believing unreservedly that the increased capacity of a railway and its stations, the economies of operation, and other advantages will bring about gradually the systematic electrification of steam railways, my wish is that the progress of the art may not be hampered and such electrification of our main lines delayed or rendered unprofitable by mistakes which experience, judgment and foresight may enable us to avoid.

213 It is my intention in this paper to direct attention to the necessity for the very early selection of a comprehensive electrical system embracing fundamental standards of construction which must be accepted by all railway companies in order to insure a continuance of that interchange of traffic which, through force of circumstances has become practically universal, to the great advantage of transportation companies and of the public.

214 Having been identified with railway operations for over forty years, and with the development of the electrical industry for twenty-five years, I feel that the time is ripe for such a selection unless we are willing to regard with complacency the extension of the existing diversified systems and the creation of conditions which will prevent the general use of the most practical methods of operation.

215 Indeed, the tendency seems to be toward diversity rather than unity, since different types of third-rail construction have been adopted, even for the several continuous-current systems in and about New York City, which renders interchange of cars or locomotives difficult or impossible.

216 Although the facts clearly show the contrary, there exists a popular impression that the electrification of railways is a simple matter, and that it requires only decisions by boards of directors to insure the immediate substitution of the electric for the steam locomotive.

217 The great difficulty in the electrification of standard railways is no longer the engineering problem of developing a locomotive and an electrical system which will operate trains, but it is a broad question of financial and general policy of far-reaching scope, considering the future electrification of railways in general as distinguished from isolated cases of limited extent, and requiring a combination of the highest engineering and commercial skill.

GAGE OF TRACK AND INTERCHANGE OF TRAFFIC

218 In the first days of railway operation, there was probably no idea of an interchange of traffic involving the use of the engines and cars of one railway upon the lines of another railway. It then made no difference whether the gage of track was 4 ft. 8½ in., the one ultimately selected, or one of a greater or lesser width by a few inches. The gage selected by Stephenson was a practical one, fortunately, since it has become almost universal, with a strong probability that it will one day be absolutely so.

219 Stephenson's successful demonstrations prompted experimenters in other countries, who naturally failed to appreciate the inconvenience and losses which were to follow the adoption of different gages. The general tendency to extend along the line of least resistance, made it inevitable that a railway once started upon a certain gage would make no change, and thus there were developed systems of railways with different gages of track. In the early days too, there were those who believed it to their advantage to establish a gage of track that would absolutely prevent the cars and engines of a connecting line from coming upon their line.

220 In some cases in the United States the difference in gage was, fortunately as it afterwards proved, only 1½ in., a difference successfully met, for the purpose of interchange of traffic, by the adoption of broad-tread wheels and minor changes in the track construction. In other cases, the gages adopted were 5 ft., 5 ft. 6 in., and 6 ft., and in some of these cases the necessity for through passenger traffic led to the changing of car trucks, at certain important places, so that passengers could be transported through to their destination without changing cars.

221 In 1878 there were in the United States eleven different gages of railroad tracks in addition to the standard gage of 4 ft. 8½ in.

222 The absolute necessity for uniformity of gage of tracks both in the United States and Canada became so apparent that in due course all of the roads which had gages wider than 4 ft. 8½ in. changed to the present standard. Among the remarkable achievements of engineering was the change of the tracks of an entire system of railway of some hundreds of miles within twenty-four hours, this change having, however, required months of preparation. The losses entailed in the change of gage and of equipment have ever since been serious burdens to most of those railways, in that the costs were in most cases covered by capital charges.

223 It may be conceded that, so far as steam railway operation

is concerned, there are now no obstacles to the interchange of traffic in the broadest sense, except in the size of vehicles in certain countries where the cost of changing tunnels and bridges would be prohibitive.

REQUIREMENTS FOR INTERCHANGE OF TRAFFIC

224 With these preliminary remarks I feel certain you will agree that to insure interchange of traffic, the fundamental requirements, so far as operation by steam is concerned, with full regard for safety, speed and comfort, are very few in number and are covered by the following:

a A standard gage of track.
b A standard or interchangeable type of coupling for vehicles.
c A uniform interchangeable type of brake apparatus.
d Interchangeable heating apparatus.
e A uniform system of train signals.

The additional fundamental requirements for electrically operated railways are:

f A supply of electricity of uniform quality as to voltage and periodicity.
g Conductors to convey this electricity so uniformly located with reference to the rails that, without change of any kind, an electrically fitted locomotive or car of any company can collect its supply of current when upon the lines of other companies.
h Uniform apparatus for control of electric supply whereby two or more electrically fitted locomotives or cars from different lines can be operated together from one locomotive or car.

225 Outside of economy in capital expenditure, and economy and convenience in operation by steam or electricity, it matters not whether each locomotive and car and the apparatus upon them differ from every other locomotive and car in size or details of construction, so long as the constructions are operative and the materials employed are used within safe limits.

DEVELOPMENT OF ALTERNATING-CURRENT APPARATUS

226 Having acquired a considerable experience in the introduction upon railways of the compressed air-brakes and in the development of automatic electro-pneumatic signals, I was led in 1885, because of its general analogy to operations with which I was familiar, to interest myself in the American patents of Gaulard and Gibbs (a Frenchman and an Englishman), covering a system of electrical distribution by means of alternating currents, with static trans-

ers to reduce these currents from the high voltage necessary
conomical transmission of electrical energy to the lower voltages
ired for the operation of incandescent lamps and other purposes.

7 No inventions ever met with greater opposition in their
nercial development than those relating to the generation,
ibution and utilization of alternating currents, and it is a matter
cord that the opponents of those interested in developing the
nating system even sought, through public meetings and the
intment of commissions, and by various extraordinary means,
fluence and prejudice public opinion.

8 Realizing the limitations of the continuous or direct-current
m, I became thoroughly convinced that the extended distribu-
of electricity for industrial purposes could be secured only by
generation of alternating currents of high voltage and their
ersion by static transformers into currents of various voltages.
vithstanding, therefore, the frank disbelief in its practical value
minent scientific authorities, among them the late Lord Kelvin,
tered actively into the development of the alternating-current
m of generation and distribution of electricity which is now
st universally accepted as the ideal.

9 By 1888 Nikola Tesla had demonstrated the practicability of
induction motors, Oliver B. Shallenberger had perfected his
r for measuring alternating currents, and it had been proved
a direct-current motor with laminated armature and fields could
erated either by alternating or by direct currents. I then became
oughly imbued with the belief that further invention and dis-
ry would in time make alternating-current apparatus practically
ersal for almost every purpose.

0 In 1892 two single-phase motors of about 10 h.p. were built
he Westinghouse company to determine the possibilities of
alternating current for traction work. These motors were
ned for 2000 alternations per minute and about 200 volts.
were of the series type, with commutators, and had a relatively
number of poles. These were placed upon a car and tested on
rt piece of track with very short curves and rather steep grades.
e was a transformer on the car on which there were several taps
the voltage was varied by means of single-pole switches. It
considered at that time that the system would be ideal for
notive work, but as there were no such projects in view, no large
rs of this type were built. This development is referred to
at length in Appendix No. 5.

231 All so-called continuous- or direct-current generators really generate alternating currents and transform them by a commutator into continuous current, and such a machine will, by the application of collector rings upon its armature, deliver both alternating and continuous currents. The use of the commutator, however, so limits the voltage that large quantities of power cannot be generated for economical transmission by direct current. A machine so constructed can also receive alternating currents through the collector rings and transform them into direct current. As thus used the apparatus is called a rotary converter. When the supply of alternating current is at very high voltage, there has to be interposed between this supply and the rotary converter a static transformer to reduce the high primary voltage to the permissible lower voltage.

ELECTRICAL SYSTEMS FOR RAILWAYS

232 As soon as these qualities of the alternating current had been demonstrated, active minds were directed toward the development of apparatus to meet conditions constantly presenting themselves, among the most important problems being the electrification of railways. In the twenty years that have elapsed, three important electrical systems for the operation of railways have been put into practical operation, all using alternating current in whole, or in part. These systems are:

a The continuous- or direct-current system, usually spoken of as the "third-rail" system, which employs alternating current for transmitting power when the distance is considerable.

b The three-phase alternating-current system with two overhead trolley wires.

c The single-phase, alternating-current, high-tension system with a single overhead trolley wire.

233 In a notable case of the latter system, namely, that of the New York, New Haven & Hartford Railroad, the motors and controlling apparatus are arranged to utilize single-phase current from an overhead trolley wire at 11,000 volts, and also to be operated by current from the 650-volt third-rail system of the New York Central & Hudson River Railroad, thus making a demonstration of the wonderful flexibility of alternating-current apparatus.

234 The problem before the officials of the New Haven road was not merely the electrification of a division of a few miles of its track, rendered compulsory by legal requirements, but the selection of a sys-

FIG. 18 SINGLE-PHASE ELECTRIFICATION OF THE NEW YORK, NEW HAVEN & HARTFORD RAILROAD

VIEW SHOWS TROLLEY WIRE SUPPORTED BY DOUBLE STEEL CATENARY CABLES SUSPENDED FROM LATTICE STEEL BRIDGES OVER THE FOUR TRACKS. THE ONLY ELECTRICAL CONSTRUCTION ON THE TRACK LEVEL IS THE SMALL COPPER BONDS CONNECTING THE RAILS.

tem which would meet the needs of a great railway covering several states and having other congested centers of traffic which it might soon be desirable to electrify. In view of the fact that there had been no considerable demonstration of the single-phase system by actual use, and that the New Haven trains would be obliged to operate upon twelve miles of lines already equipped with the direct-current third-rail system, it must be conceded that the directors and management of the New York, New Haven & Hartford Railroad showed great courage and confidence in the judgment of their experts and rendered to all other railroads a service of the highest character when they selected the single-phase system for the electrification of the line mentioned.

235 As the single-phase method of operation is comparatively recent and is not so well known as the other systems, extended particulars are given in the appendices upon the extent of operation by this system, and upon the results attained in its use by the New York, New Haven & Hartford Railroad. The important experiences gained on that railroad furnish very important data to aid in the selection of a uniform system of electrical railway operation.

236 The paper[1] by Mr. George Gibbs, chief engineer of electric traction of the Pennsylvania Railroad, with reference to the electrifications by that company, submitted in June of this year to the International Railway Congress at Berne, Switzerland, gives most valuable particulars in regard to the practical electrical operation of a standard railway.

237 When the officials of the New York Central Railroad and those of the New York, New Haven & Hartford Railroad, who now have had an unusual experience, also present their available facts as to cost of installation, of maintenance and of operation, the railway world will have very complete information.

238 The results of the working of the three-phase system in Italy and Switzerland have been very prominently before the world for several years, and its successful use there has been a material factor in the development of confidence in electricity for the operation of railway trains. At the present time, the Italian Government is installing upon the Giovi line, which is a heavy-grade branch leading out of Genoa, a service for which twenty locomotives, rated at 2000 h.p., are now being constructed in Italy. The operation of this

[1] The report is entitled Electric Traction: Electric Traction on Large Railroads; Continuous Current; Alternating Current (Monophase or Polyphase); Comparative Net Cost. It appears in the Bulletin of the International Railway Congress Association, under Question 8, Report No. 2, by George Gibbs.

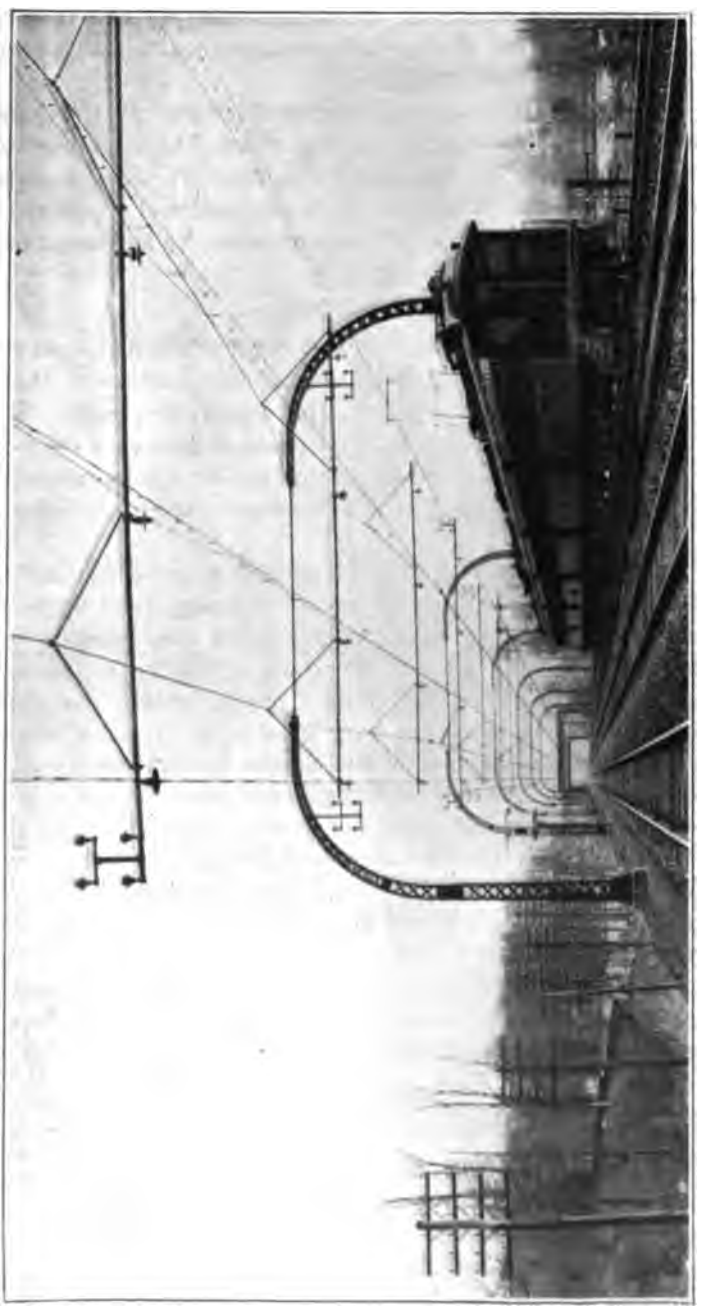


FIG. 19 MULTIPLE UNIT TRAIN FOR SUBURBAN SERVICE; OVERHEAD CONSTRUCTION OF NEW TYPE DEVELOPED BY THE NEW YORK, NEW HAVEN AND HARTFORD RAILROAD

much more extensive plant will afford additional valuable information as to the cost of installation and operation, and the advantages of the three-phase system.

239 The equipment of the power houses which generate the current is essentially similar in the three systems which I have enumerated; but the systems differ in the kind of motors and the auxiliary apparatus for controlling them, and in the methods and apparatus for transmitting the current from the power house to the locomotive or car.

RAILWAY MOTORS

240 Essential requisites in a railway motor are that it shall start its load and quickly accelerate it to the required speed, and that it shall operate continuously at any desired speed, or speeds. Railway conditions make it desirable that speeds should vary from the lowest to the highest schedule speeds required for regular operation, both for the movement of freight and passengers, and for making up time.

241 The steam locomotive, which is limited in power by its boiler capacity, is capable of continuous operation at any speed up to the maximum, but the maximum speed in a given case depends both upon the length of the train and the grade of the track. It automatically slows down when ascending a grade, so that the actual horsepower developed does not vary greatly at different speeds. The limitation of the capacity of the electric locomotive is not the power available, as is the case with the steam locomotive, but in the capacity of the motors, and is usually fixed by the heating of their coils. An electric locomotive may safely develop for a short time an output which far exceeds its normal continuous capacity. The power and speed characteristics of electric locomotives therefore differ from those of steam locomotives.

242 The three types of electric motors have certain fundamental differences in speed performance which are important factors in determining the advantages, disadvantages and limitations of the several systems.

THE DIRECT-CURRENT MOTOR

243 The characteristics of the direct-current series railway motor are well known. It automatically adjusts its speed in accordance with the load, running more slowly if the weight of the train be greater, or the grade steeper. The speed with a given load, however, is definite; it is dependent upon the voltage applied to the motor and cannot

FIG. 20 PENNSYLVANIA ELECTRIC LOCOMOTIVE WITH ALL STEEL CAR TRAIN FOR OPERATION INTO THE NEW YORK STATION

readily be varied. It is true that the speed can be decreased by inserting a resistance in the motor circuit, but this is wasteful and is inadmissible except as a temporary expedient. It is true also that the motors may be connected in series, thus dividing the pressure between two motors, and thereby reducing the speed one-half; or if among four motors, to one-quarter speed. As the system of current supply involves a fixed voltage, it is obvious that for emergencies no speeds much above the maximum speed determined in the construction of the motor can be obtained. Furthermore, on account of the high cost involved in maintaining a practically constant voltage throughout the system, the voltage supplied to the motors often decreases considerably at the end of long lines, at the time of heavy load, thereby further reducing the speed attainable. It often happens in railway service that a locomotive should be operated somewhat above the normal speed, and sometimes a locomotive designed for freight service has to be pressed into passenger service. In such cases the speed with the direct-current locomotive would be considerably less than that necessary to maintain the schedule speed. A special form of field control can be used, in certain cases, for varying the speed, although this has so far been utilized to a very limited extent.

THE THREE-PHASE MOTOR

244 On the three-phase system, the motor is inherently a constant-speed motor; it runs at approximately the same speed at light load and at full load; it runs at nearly the same speed up a grade as on level track, although the horsepower required on the grade may be several times that on the level. Conversely, it can run no faster on a level than it can climb a grade. In order to give a lower speed, however, the motors may be arranged upon the locomotive in pairs in a manner equivalent to the arrangement of two continuous-current motors in series, just described. Motors may also be arranged for two or more speeds, but this involves some complication in windings and connections. In all cases lower speeds can be secured by the introduction of resistances which increase the losses and lower the efficiency. In no case can the speed in any of the arrangements of motors be appreciably higher at very light load than it is at full load.

245 The motors are of the induction type without commutators and their inherent limitations, and are of relative simplicity in construction. The current is usually supplied at 3000 volts from two overhead lines through two sets of current collectors.

246 With three-phase motors as now constructed and arranged on locomotives, it is possible with no additional complication to utilize the motors when locomotives are moving trains upon a scending grade, that they become generators and return current to e line, a feature of value in certain mountainous districts but not of ntrolling importance in the selection of a universal system.

THE SINGLE-PHASE MOTOR

247 The single-phase railway motor is a series motor with speed aracteristics very similar to those of the direct-current motor,

. 21 Typical Section, showing Third Rail, Transmission Line and Signal Bridge of the New York Central and Hudson River Railroad

the speed at a given voltage is greater or less, depending upon the d. The speed with a given load is also greater or less, depending on the pressure applied to the motor; and this is not limited, as h direct-current motors, to that supplied by the circuit, and one-half and one-fourth of that pressure, but is capable of adjustnt to any desired degree of refinement by means of auxiliary conctions from the secondary winding of the transformer on the locotive, which is necessary for reducing the line voltage of 11,000 volts the lower voltage required by the motors. Not only may numerous tages less than the normal be arranged for lower speeds, but higher tages can be provided to make possible speeds considerably above

the normal. In this simple manner a wide range of efficient speed adjustment is secured which is impossible with other systems.

248 Like the throttle lever of the steam locomotive, the control lever of the single-phase locomotive may be placed in any one of its numerous notches to maintain the required speed. This facility of efficient operation over a wide range of speed and power requirements is one of the especially valuable features of the single-phase system. This difference, however, may be noted: the ability of the steam locomotive to maintain its speed continuously with heavy loads depends upon the capacity of the boiler; on the other hand, the electric locomotive has an ample supply of energy available, drawn from a large power house, and the limit of its endurance is determined by the safe temperature of the motor.

249 The question of determination of the frequency for use on single-phase railways is one of very great importance. Twenty-five cycles is in general use for power transmission purposes and has been adopted by nearly all the single-phase railroads now operating. The Midi Railway of France has adopted 15 cycles. The lower frequency permits of a marked reduction in the size of a motor for a given output, or conversely of a considerable increase in output from a motor of given dimensions and weight. Three-phase installations in nearly all cases employ approximately 15 cycles. The choice of frequency is one of the most involved, difficult and important problems now presented for solution.

SUMMARY

250 Locomotives equipped with each of the three types of motor have been in successful operation and have demonstrated their usefulness, capacity and reliability in practical railway service. The three-phase motor, having a definite constant-speed characteristic, is particularly adapted to certain conditions; but on the other hand it has a less general adaptability to the ordinary varying conditions of railway operation. The single-phase motor has a facility of voltage control which gives an efficient means of speed adjustment, and is in this particular superior to other systems. The relative weights and costs of the several types of motors, and of the locomotives designed to accommodate them, depend upon so many conditions that comparisons must necessarily be general. It will be found, however, that these differences in locomotive cost are in many cases more than offset by the cost of the other elements in the electrical system.

FIG. 22 NEW YORK CENTRAL AND HUDSON RIVER RAILROAD LOCOMOTIVE DRAWING 20TH CENTURY LIMITED TRAIN

251 The control apparatus for all types of locomotives has been developed so that it is reliable and convenient in operation. For each system a small master controller serves to operate by auxiliary means the necessary electric switches for the control of the motors of one locomotive, or to operate simultaneously as a single unit the motors on two or more locomotives or cars in a train.

Transmission of Power from Power House to Locomotive

252 The controlling factor in the cost of electrification in nearly all cases is the system for transmitting power from the power house to the locomotive, and not the locomotive itself. The choice between the several systems must, therefore, be based upon a comparison of the complete systems. The differences between the methods of transmitting power are of far greater importance than the differences between power houses or between locomotives. The current for all systems is generated in usual practice as high-tension alternating current, for the reason that electric energy can be most economically transmitted by high-tension alternating current even though it is in some cases converted into direct current.

253 The transmission systems in use for the three types of locomotives are illustrated in Appendix No. 3. Even a superficial glance at these diagrams brings several points into prominence, as follows:

THE DIRECT-CURRENT SYSTEM

254 For the direct-current locomotive the apparatus which intervenes between the alternating current-generator and the locomotive consists of a number of links or elements through which the electric energy must pass, one after the other. These consist of:

a Raising transformers in groups of three.

b A transmission line of three wires, sub-stations, which require attendance, containing

c Transformers in groups of three, and

d Rotary converters for receiving the alternating current and delivering direct current.

e A third-rail contact conductor, which for heavy work must often be supplemented by copper feeders.

f The track return circuit, which must be provided with heavy bonds, and in certain cases supplemented by feeders and so-called negative boosters.

255 It is necessary to maintain the alignment of the third rail within close limits both in its distance from the track rails and in its

FIG. 23 MULTIPLE UNIT TRAIN IN SUBURBAN SERVICE ON NEW YORK CENTRAL AND HUDSON RIVER RAILROAD

elevation above them, as the contact shoe can have only a small range of automatic adjustment.

THE THREE-PHASE SYSTEM

256 For the three-phase locomotives the respective links between the generator and the locomotives are:

a Raising transformers in groups of three.
b Transmission line of three wires.
c Sub-station transformers in groups of three.
d Two overhead wires as the contact system.
e A track return which usually requires nothing but inexpensive bonding.

257 The two overhead trolley wires require a double system of overhead construction, as the wires must be kept separate and well insulated from one another; the two must be maintained at equal height above the track and at switches and cross-overs the construction is complicated.

THE SINGLE-PHASE SYSTEM

258 For single-phase locomotives there is:

a A raising transformer.
b A transmission line of two wires and sub-stations widely spaced, each containing
c A lowering transformer, which supplies
d A single trolley wire.
e A track return, usually requiring nothing but inexpensive bonding.

259 In certain cases where the distance from the power station is not more than 15 or 20 miles, the single-phase trolley can be supplied directly from the power house, so that only one single element, i.e., the trolley wire, intervenes between the generators and the locomotives.

260 The single trolley wire permits a relatively wide range in height, as the pantograph trolley automatically adjusts itself to the position of the trolley wire. In some cases the wire has a normal height of 22 ft., but is carried under bridges where the limit is 15½ ft.

261 The three types of railway motors, and the three respective systems for conveying power from the generating station to the locomotives, have all successfully demonstrated their ability to operate railway trains. It is not my purpose to urge the adoption of a particular system, but rather to point out some of the well-known char-

Overhead Construction on Italian Railways, Lecco-Calolzio Line

stics of these systems which have a bearing upon their limita- and their general adaptability to railway conditions, and to urge reat gain which will result from a single universal system.

As the electrical manufacturing companies with which my is associated manufacture and install all kinds of direct and ating-current apparatus, I may be pardoned for saying that e not permitted my judgment to be influenced by any personal ial interests, and that I have treated this subject so as to give s the benefit of a long experience, acquired under circumstances favorable to ascertaining the facts.

REQUISITES FOR A UNIVERSAL ELECTRIC SYSTEM

In selecting a proper electrical system for railway operation, l probably be generally conceded that the following elements prime importance:

a The electric locomotives should be capable of performing the same kinds of service which the steam locomotives

now perform. This will be most readily secured by electric locomotives which can practically duplicate the steam locomotives in speed and power characteristics. This includes a wide range of performance, embracing through passenger service at different schedule speeds; local passenger service; through freight service in heavy trains; the handling of local freight by short trains; and a variety of switching, terminal and transfer movements. This naturally calls for wide variation in tractive effort and in speed, both for the operation of different kinds of trains, and also for the operation of the same train under the varying conditions usually incident to railway service.

b The electric locomotive should be capable of exceeding the steam locomotive in its power capacity. It should be able to handle heavier trains and loads, to operate at higher speeds, and in general to exceed the ordinary limits of the steam locomotive in these regards. The readiness with which several electric locomotives can be operated as a single unit enables any amount of power to be applied to a train.

c The electric system should adapt itself to requirements beyond the ordinary limitations of the steam locomotive in small as well as large things. It should be adapted for use on branch lines, and for light passenger and freight service similar to that so profitably conducted by interurban electric roads, which in many cases run parallel to steam roads, not only taking away the traffic of the steam roads, but building up a new and highly profitable traffic, both in passenger and in express service.

d A universal electrical system requires that power should be transmitted economically over long distances and supplied to the contact conductor. The system should utilize the most highly perfected apparatus for the electric transmission of energy and its transformation into suitable pressures for use.

e The contact conductor in an ideal system should be economical to construct, both for the heaviest locomotives where the traffic is dense, and for light service on branch lines. It should impose minimum inconvenience to track maintenance; should give minimum probability of disarrange-

ment in case of derailment, or in case of snow and sleet, and should in general be so placed and constructed as to give a maximum assurance of continuity of service.

264 The use now made of electricity in steam railway service has been brought about, generally speaking, through compulsion. The steam locomotive has reached its limitations and has been found unsuitable and inadequate in tunnels or in terminal service. Even where other considerations may have been controlling, the problem has usually been a specific one of electrifying a relatively small area. The problem has been solved by considering those factors which were of immediate importance, without giving weight to uniformity with other systems or of extension.

265 Now the natural course of development will be the extension of these limited zones, until after a time they meet. Then there will arise great inconvenience and expense if the systems are unlike. For the present it may be a matter of little moment whether different systems have their contact conductors in the same position, or whether the character of the current used is the same or different. As previously stated, in the early days of railroading, it was of little consequence whether the tracks of the different systems in various parts of the country were alike or unlike, but later it did make a vital difference, and the variation resulted in financial burdens which even yet lie heavily on some railways. It is this large view into the future of electrical service which should be taken by those responsible for electric railway development.

THE FUTURE OF ELECTRIFICATION OF RAILWAYS

266 The complete electrification of a railway will necessitate a rearrangement of ideas and practices in regard to operations. Coaling and watering places will not be needed; passenger trains will be differently composed, some classes being of less weight; and they will operate more frequently, thus promoting travel; other trains will be heavier than at present, or will operate at higher speeds; and branch lines, by the use of electrically fitted cars, can be given a through service not now enjoyed.

267 The movement of freight will undergo great changes, due to the fact that electric locomotives can be constructed with great excess capacity, enabling them to move longer trains at schedule speed on rising gradients.

268 The large percentage of shunting operations due entirely to the use of steam locomotives will no longer be required.

269 The railway companies can combine upon some coöperative plan for the generation of electricity, thereby effecting large savings in capital expenditures; and can utilize their own rights of way for the transmission of the current, not only for the operation of trains but for many other useful purposes.

270 Notwithstanding the fact that great strides have already been made in cheapening the cost of generating electricity by steam engines, I foresee, from the progress made in the development of gas and oil engine power, a still further reduction in cost which will accelerate the work of electrifying existing railways.

271 One important aspect of this great question will engage the thoughtful consideration of every government, namely, the military necessity for uniform railway equipment in time of war.

272 There will be serious difficulties to surmount in the selection of a general system. There naturally will be arguments in favor of one or another of the systems now in use and the inclination of those who have adopted a particular system to advocate its general use. There will be enthusiastic inventors, and there will be many advocates of the common view, namely, that there is room for several systems and that each system will best meet the requirements of a particular case. There will be those who give undue weight to some feature of minor importance, such as a particular type of motor or of locomotive, instead of giving a broad consideration to the whole system, and recognizing that, in the general problem of railway electrification, facility and economy in transmitting power from the power house to the locomotive are of controlling importance.

273 Were there now only one system to be considered, there would be a concentration of the energy of thousands on the perfecting and simplifying of the apparatus for that system, to the advantage of railway companies and of manufacturers.

274 In conclusion, I can only repeat, and earnestly recommend to the serious consideration of railway engineers and those in authority, the pressing need of determining the system which admits of the largest extension of railway electrification and of a prompt selection of those standards of electrification which will render possible a complete interchange of traffic in order to save expense in the future and to avoid difficulties and delays certain to arise unless some common understanding is arrived at very shortly.

APPENDIX No. 1

THE SINGLE-PHASE SYSTEM ON THE NEW YORK, NEW HAVEN & HARTFORD RAILROAD

275 The most important installation of single-phase apparatus is that of the New York, New Haven & Hartford Railroad, leading out of New York City. Practically all the railroad service between New York and Boston, as well as the New England States, is over the four tracks of this railroad. The trains pass into the Grand Central Station in New York City over the lines of the New York Central & Hudson River Railroad, which is electrically equipped with the third-rail system for operation by direct current at 650 volts. Selection of the system for the New Haven railroad was restricted by the necessity of operating the New Haven trains over the New York Central tracks; but the decision was in favor of the single-phase system, notwithstanding the limitation that the locomotives must operate successively both by single-phase current and direct current.

276 The trains of the New Haven system leaving the Grand Central Station pass over 12 miles of the tracks of the New York Central system, operating from the third rail by direct current. They then pass to the New Haven tracks at full speed, receiving alternating current at 11,000 volts from the overhead trolley wires which extend 21 miles to Stamford, a total distance of 33 miles from New York, this being the end of the initial installation of the single-phase system.

277 The power house is located near the Stamford end of the electrified section and contains four 11,000-volt turbo-generators having an aggregate capacity of over 16,000 kw. The current passes directly from the generators to the trolley wires, as illustrated in Fig. 35 and in the last diagram of Fig. 36.

278 The overhead trolley system consists of a steel contact trolley wire suspended every 10 ft. from a copper trolley wire, which in turn is suspended at intermediate points from two steel catenary cables by triangular-shaped hangers. These cables are supported upon insulators resting upon steel bridges spaced at distances of 300 ft. along the right of way. The construction is shown in Fig. 18 of the paper.

279 As in general there are four tracks and in some cases more, the comparatively light steel bridges are made to span the right of way and to carry as many sets of the trolley conductors as there are tracks. Stronger bridges to which the catenary cables are anchored are located about every two miles. At certain points these anchor bridges are utilized for supporting the block signals and also to carry oil circuit breakers which permit the trolley wires to be sectionalized for service operation or in emergencies. Normally all the trolley wires and the supporting cables over all the tracks are connected together electrically and also to the source of supply at the power house

280 There are 41 locomotives in regular operation, and also four motor cars with six trail cars operating on the multiple unit system in suburban service. The alternating current is taken from the overhead trolley wire by a pantograph which presses a shoe against the wire. The direct current on the New York Central zone is obtained from the third rail by means of ordinary sliding contact shoes. Both the pantograph and the contact shoes are manipulated by compressed air. The locomotive is described in Par. 291.

281 For reasons of economy in operation the locomotives were built under the requirement that each should be capable of hauling a 200-ton train from New York to New Haven, making all station stops in accordance with the regular schedules, or an express train of 250 tons, and that the locomotives should be so arranged that two or more could be operated by a single engineer for the movement of heavier trains. The particular size selected permits about 75 per cent of the trains to be operated by a single unit.

TABLE 23 RECORD OF SINGLE-PHASE SERVICE

NEW YORK, NEW HAVEN & HARTFORD RAILROAD FOR 12 MONTHS

	Total Miles Run	No. Locomotive Delays	Miles Run per Locomotive Delay	No. of Power House Delays	No. of Line Delays
1909					
April	146,189	9	16,243	..	3
May	155,551	25	6,222	1	3
June	166,759	14	11,911	..	4
July	183,434	13	14,110	..	2
August	177,714	14	12,694	..	5
September	189,656	14	13,547	..	1
October	174,400	11	15,854	1	4
November	173,370	10	17,337	..	1
December	167,808	23	7,296	..	3
1910					
January	163,274	28	5,831	..	2
February	138,929	12	11,577	..	1
March	156,901	12	13,075	..	1

282 During the past year, the electric service has surpassed in efficiency all records previously obtained on this division with steam locomotives. The actual figures are given in Table 23, which covers the movement of passenger trains over the 12 miles of third-rail operation and 21 miles of single-phase operation, for which 41 locomotives, that have been used from 22 to 33 months, were available.

283 The early fears as to difficulties in commutation have been dispelled by the records of performance, as many of the motors have operated over 100,000 miles without turning or even sandpapering the commutators, and the brushes show an average life of 40,000 to 45,000 miles.

284 The average number of miles run per locomotive delay during the year exceeds 12,000, equivalent to a dozen trips between New York and Chicago, or thirty trips between London and Glasgow.

285 The locomotive delays (many of which only slightly exceeded one minute duration) include not only those from electrical causes, but from mechanical

s well, such as loose tires, burst airhose, hot journal boxes, frozen steam . A comparatively large number of delays in December and January to the very severe weather and the unusual amount of snow and ice. omotives have been making regularly an average of about four and one- of 33 miles per day, hauling trains 25 to 50 per cent heavier, or even the case of express trains, than the locomotives were guaranteed to Most of the locomotives have run about 100,000 miles, but there is ore than one (which is 2½ per cent of the whole number) out of service s, a record said by the officials of the company to be much better than eam locomotives which were replaced. These officials also say that the aintenance per mile and the number of miles run per electric locomotive ore favorable than with steam locomotives, even with the present very of 33 miles.

he cost of maintenance of the distribution system is relatively small l with that of the low-voltage third-rail system. The delays due to the ion lines and overhead construction, though few in number, include ught about by extraordinary conditions, such as steam from switch nd by wrong operation of switches.

he heaviest traffic on the New York division of the New Haven road, occasion on which delays would be most deplored, is on the day nual intercollegiate football game at New Haven. The service on or 1908 and 1909 was as follows:

	1908	1909
rains	128	126
ains	30	29
l trains	158	155
f train delays	2	0
ation of delays	17 min.	

n considering the capability of the single-phase system for continuous nce, the record of the six single-phase locomotives in service at the St. nel of the Grand Trunk Railway is worthy of mention. These loco- ave now been running two years and have made about 70,000 miles raging about 100 miles per day, or 25 trips of 4 miles. It has not been to use a steam locomotive since the regular electric service was started 8) and during the last 12 months the service has been responsible for rain delay, of eight minutes. The locomotive is described in Par 292.

APPENDIX No. 2

DATA ON ELECTRIC LOCOMOTIVES OF AMERICAN DESIGN

289 The locomotives on which data are given were built for heavy railway service. They are for passenger service and for combined passenger and freight, and include locomotives for direct current, three-phase current, and single-phase alternating current, and others adapted for operation on either single-phase alternating current or direct current.

290 A brief description of these locomotives follows, including mention of some of their notable features.

LOCOMOTIVES OF THE WESTINGHOUSE ELECTRIC & MFG. CO.

291 Referring to Table 24, the first column covers locomotives built for the New York, New Haven & Hartford Railroad, for operation on their electrified zone between New York and New Haven. The electrical system demanded that the locomotives be capable of operation both on single-phase and direct current. There are 41 of these locomotives in operation. A gearless concentric motor for each driving axle is mounted on a quill flexibly connected to the driving wheels. The dead weight on the axles is thus reduced to a minimum. Two of these locomotives are shown attached to the train in Fig. 18 of the paper.

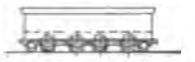
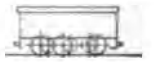
292 The second column covers locomotives built for the Grand Trunk Railway for operation in the St. Clair Tunnel under the St. Clair River. These locomotives are designed for operation with single-phase current only. They are handling the entire freight and passenger traffic through the tunnel. A report of the operation of these locomotives is given in Par. 288, Appendix No. 1. The locomotive is shown in Fig. 25.

293 The third column covers locomotives built for the Pennsylvania Railroad for operation in their New York tunnel. They are for passenger service only and operate on direct current at 600 volts on the conductor. The first locomotive has been run 17,000 miles on test. The center of gravity of these locomotives is high, as the motor is mounted well above the driving axles. The transmission from motor to wheels is by cranks and connecting rods. These parts are protected from possible damage due to short circuit by interposing between the armature and its shaft a friction clutch which will slip before damaging stresses are imposed on the transmission. The motors are the largest railway motors ever built and are provided with commutating poles, making possible the use of a shunted field control which is applied to these locomotives. The locomotive is shown in Figs. 26 and 27.

294 The fourth column covers a locomotive built for the New York, New Haven & Hartford Railroad for use in high-speed freight and medium-speed passenger service. It also is fitted for operation both with single-phase and direct-current

TABLE 24 DATA ON ELECTRIC LOCOMOTIVES OF AMERICAN DESIGN

BUILT BY THE WESTINGHOUSE ELECTRIC & MFG. CO.

					
Built for	New Haven	Grand Trunk St. Clair Tunnel	Pennsylvania	New Haven	New Haven
Electric system	A.C., D.C.	A.C.	D.C.	A.C., D.C.	A.C., D.C.
Service	Passenger	Frt. & Pass.	Passenger	Frt. & Pass.	Frt. & Pass.
First placed in service	July 1907	February 1908	17,000-mile test	3000-mile test	building
No. in service or on order May 1910	41	6	24	1	1
No. motors per locomotive	4	3	2	4	2
Armature diameter, inches	39½	30	56	39½	76
Core length, including vent opening, inches	18	14¾	23	13	13
Weight one motor, lb	16,420	15,660	45,000	19,770	41,600
Weight all motors on locomotive	65,680	46,980	90,000	79,080	83,200
Weight all electrical parts	110,400	58,400	127,200	130,000	135,000
Weight all mechanical parts	94,100	73,600	204,800	130,000	125,000
Weight complete locomotive	204,500	132,000	332,000	260,000	260,000
Weight on driving wheels	162,000	132,000	207,800	180,000	180,000
Weight complete locomotive for A.C. operation	196,000	132,000	D.C.	241,000	240,000
Max. guar't'd speed, miles per hr.,	about 86	30	about 80	45	45
Feature limiting speed	track	armatures	connecting rod	armatures	armatures
Max. tractive effort	19,200	43,800	69,300	40,000	40,000
Loco. wt. in excess of 18% adhesion Max. T.E., A.C. operation	88,700	none	none	18,500	17,500
Designed for trailing load, tons	250	500	550	{1500 freight / 800 pass.	{1500 freight / 800 pass.
Balance speed on level with above load	about 75	about 25	60	{35 freight / 45 pass.	{35 freight / 45 pass.

It has been run approximately 3000 miles in test service, actually hauling regular freight trains, including the steam locomotives, over the electrified section of the railroad on the normal schedules for the movement of these trains. A pinion at each end of the motor meshes with a flexible gear whose center is rigidly secured to the quill surrounding the axle, the flexible gear overcoming the difficulties in securing tooth alignment and division of load which are liable to occur when rigid twin gears are used. It is the only electric locomotive equipped with spur-geared motors which are bolted rigidly to the spring-supported parts of the locomotive. Each driving wheel is driven through helical springs, the arrangement being such that the driving wheel has practically free vertical play. The locomotive has two trucks, the drawbar pull being transmitted

FIG. 25 SINGLE-PHASE LOCOMOTIVE FOR PASSENGER AND FREIGHT SERVICE IN ST. CLAIR TUNNEL OF GRAND TRUNK RAILWAY

through the truck frames. The body is spring-mounted on friction plates in place of being carried on truck center pins in the usual manner. It is an exceptionally easy riding machine with very low rolling friction. The performance has been satisfactory, and a speed of 40 miles per hour was attained on level track with a 1600-ton train. See Figs. 28 and 29.

295 The fifth column covers a locomotive for the same railroad and service as that just described. The comparison between geared and connecting-rod motors for identical service is a very interesting feature of this development. The weights given in both the fourth and fifth columns are those on which locomotives of these types would generally be built. The actual locomotives are somewhat

heavier, due to particular features of design not inherent in the type. The effect on the connecting rods and pins of the pulsating torque of a single-phase current is avoided by the introduction of a flexible connection between the armature and its shaft. This locomotive has not been tested.

296 These last two locomotives were ordered by the New Haven road to demonstrate the practicability of electric traction for freight service and to assist in determining the most suitable kind or type of locomotive.

LOCOMOTIVES OF THE GENERAL ELECTRIC COMPANY

297 The first column of Table 25 covers locomotives built for the New York Central & Hudson River Railroad for operation on the electrified zone of the New York City terminal. Forty-seven of these locomotives are in use, the first having been put in operation in July 1906. They are used for passenger service only, and operate on direct current at 600 volts. The mechanical equipment of this locomotive consists of a main driving wheel base with four driving axles and a four-wheel guiding truck at either end. The motor is of the bi-polar gearless type, the armature being mounted directly on the driving axle, and the mechanical structure of the locomotive forming a portion of the magnetic circuit of the motors. The characteristic feature of the locomotive is the simplicity of its electrical and mechanical construction, which contributes to its high efficiency and low maintenance cost. The locomotive is shown in Figs. 22 and 30.

298 The second column of Table 25 covers locomotives built for operation at the Detroit River Tunnel. These are to be used for both freight and passenger service between Detroit, Mich., and Windsor, Ont., and will be operated at 600 volts, direct current. The running gear consists of two trucks connected together with a massive hinge so as to form a single articulated wheel base, and buffers carried on the outer end frames of the trucks. The motor is of the direct-current geared type with commutating poles and is interesting as the first application of the commutating pole motor to this class of service. Twin gearing is used between the motor and driving axle, and consists of a pinion at each end of the armature shaft and a corresponding gear on the axle. The use of twin gearing relieves the armature shaft of torsional strains and maintains the parallelism of the shaft and axle. Five of these locomotives have been built and are awaiting completion of the tunnel. While they are not in actual operation, extensive tests made on a test track in hauling and accelerating freight trains up to 1500 tons in weight have proved that this type is very satisfactory for the service.

299 The third column covers locomotives built for the Baltimore & Ohio Railroad for operation of both freight and passenger service through the Baltimore Belt Line Tunnel. Two of these locomotives are in use and operate on direct current at 600 volts. The general design is similar to the Detroit Tunnel locomotive described above and the same type of motors are used, but the motors are geared for higher speed in order to meet the speeds required by passenger service on the relatively lighter grades of the Baltimore Tunnel.

300 The fourth column covers locomotives built for the operation of freight and passenger trains through the Cascade Tunnel of the Great Northern Railway. These locomotives are designed for three-phase operation at 25 cycles and 6600 volts on the trolley. The mechanical structure consists of an articulated wheel base similar to that of the Detroit River Tunnel locomotive described above. The a motor is three-phase induction motor with external secondary resistance and

FIG. 26 PENNSYLVANIA DOUBLE ARTICULATED LOCOMOTIVE FOR THE NEW YORK TUNNEL SERVICE

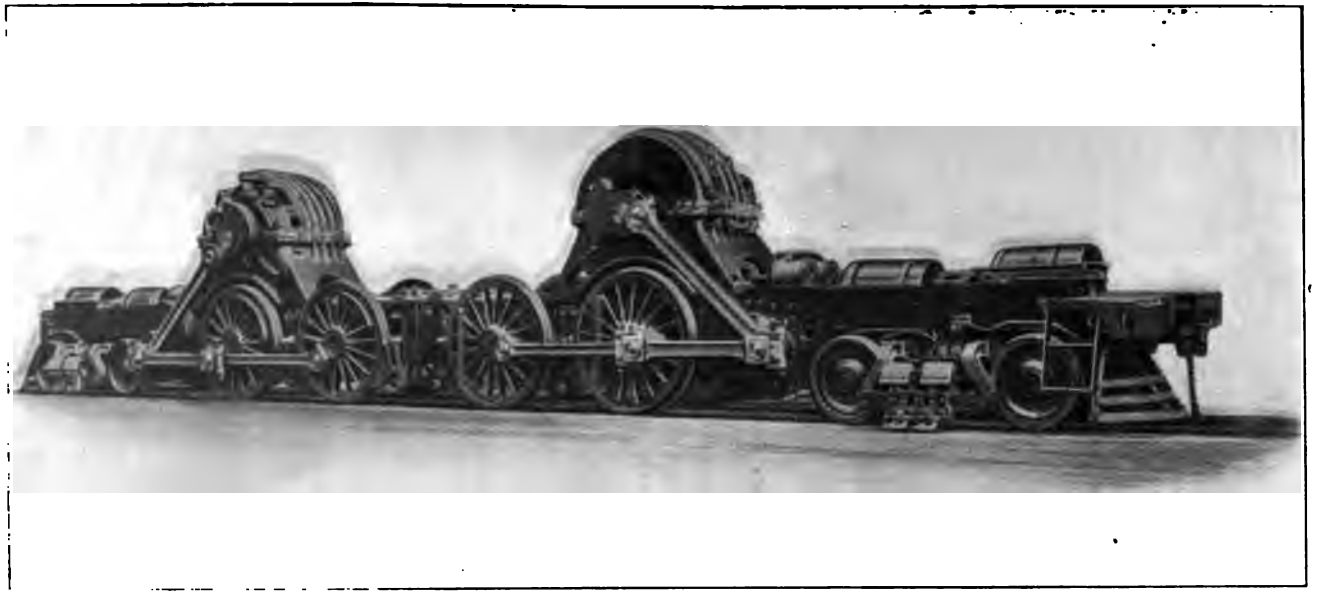


FIG. 27 UNDER FRAMES, MOTORS AND DRIVING MECHANISM OF PENNSYLVANIA DOUBLE ARTICULATED LOCOMOTIVE FOR NEW YORK TUNNEL SERVICE

FIG. 28 SINGLE-PHASE AND DIRECT-CURRENT LOCOMOTIVE FOR PASSENGER AND FREIGHT SERVICE ON THE NEW YORK, NEW HAVEN & HARTFORD RAILROAD
MOTORS WITH FLEXIBLE TWIN SPUR GEARS ARE PLACED DIRECTLY OVER DRIVING AXLES

fitted with a gear at each end of the armature shaft. The service for which they are ultimately designed is the operation of a division 57 miles long with ruling

FIG. 29 VIEW SHOWING ARRANGEMENT OF MOTORS OVER DRIVING AXLES FOR LOCOMOTIVE ILLUSTRATED IN FIG. 28

TABLE 25 DATA ON ELECTRIC LOCOMOTIVES OF AMERICAN DESIGN

BUILT BY THE GENERAL ELECTRIC COMPANY

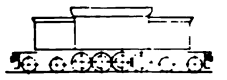
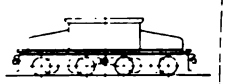
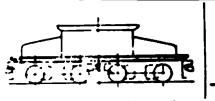
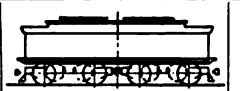
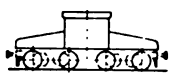
					
Built for	N. Y. C. & H. R. R. R.	Detroit River Tunnel	B. & O. R. R.	Great Northern	Paris-Orleans
Electric system	D.C.	D.C.	D.C.	3-phase	D.C.
Service	Passenger	Frt. & Pass.	Frt. & Pass.	Frt. & Pass.	Passenger
First date in service	July 1906	tests completed	March 1910	July 1909	1899
No. in service or on order May 1910	47	6	2	4	11
No. motors per locomotive	4	4	4	4	4
Armature diameter, inches	29	25	25	35¾	23½
Core length, including vent opening, inches	19	11½	11½	16¼	12
Weight one motor, lb.	18,150	10,560	10,560	15,000	8,855
Weight all motors on locomotive	72,600	42,240	42,240	60,000	35,420
Weight all electrical parts	91,200	54,000	54,000	109,000	42,500
Weight all mechanical parts	138,800	146,000	130,000	121,000	67,500
Weight complete locomotive	230,000	200,000	184,000	230,000	110,000
Weight on driving wheels	141,000	200,000	184,000	230,000	110,000
Weight complete locomotive for A.C. operation	D.C.	D.C.	D.C.	230,000	D.C.
Max. guaranteed speed, miles per hr.	75	30	55	30	45
Feature limiting speed	track	armature	armature	armature	armature
Max. tractive effort	47,000	67,000	61,000	77,000	37,000
Loco. wt. in excess of 18% adhesion Max. T.E., A.C. operation	none	none	none	none	none
Designed for trailing load, tons...					
Freight		900 on 600 2% grade	850 on 500 1½% grade	500 on 2.2% grade	
Passenger					
Balance speed on level with above load	435 / 63	Freight 20.5 / Pass. 22	Freight 26 / Pass. 30	15	300 / 32

FIG. 30. ELECTRIC LOCOMOTIVE ON THE NEW YORK CENTRAL & HUDSON RIVER RAILROAD

grades of 2.2 per cent and an average grade of 1.55 per cent. Four of these locomotives are in service and it may be of interest to note that they were involved in the disastrous avalanche of March 1, 1910, which swept through the electrified yards at Wellington, Wash. The locomotive is shown in Fig. 31.

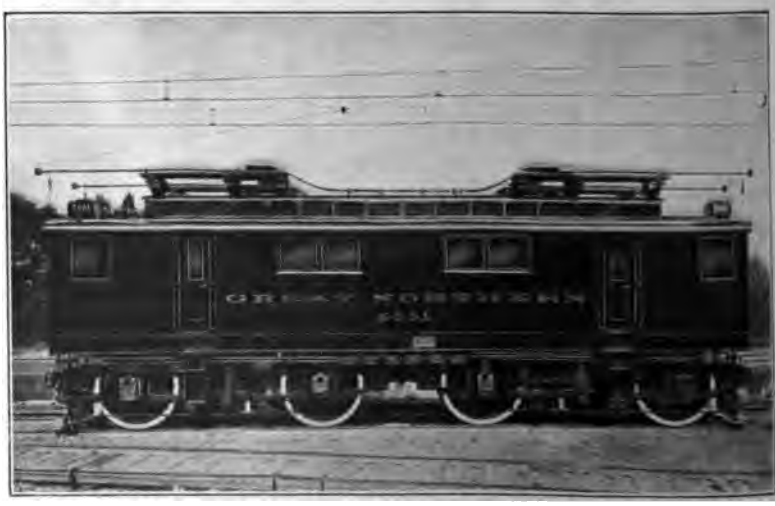


FIG. 31. ELECTRIC LOCOMOTIVE ON THE GREAT NORTHERN RAILWAY

301 The fifth column covers locomotives built for the Paris-OrleansRailway, for use in hauling passenger trains from əɥ Austerlitz Station to the Quai d'Orsay. They are designed for operating on 600 volts, direct current. These locomotives are historically of interest, the first one of them having been delivered in 1899, and twelve being now in service. Each locomotive has two independent trucks, each truck equipped with two geared motors, and carrying weight of cab and platform on the center pin with draft gear and buffer attached to this platform. This represents a type of locomotive of which a large number have been built, and which has proved highly satisfactory for light and medium classes of service.

APPENDIX No. 3

COMPARISON OF SYSTEMS OF ELECTRIFICATION

302 The salient features of the three systems of railway electrification as presented in a number of diagrams so arranged as to permit of a ready comparison between their essential characteristics, particularly in the circuits and apparatus which transmit the power from the power station to the locomotive.

303 The perspective sketches, Figs. 32 to 35, show the commonly used types of apparatus and circuits in a simple and elementary way, as only a single generator and a single sub-station, containing but one group of units, are shown, and auxiliaries such as switchboard apparatus are altogether omitted.

304 Fig. 32, showing the direct-current system, illustrates the alternating-current generator, the three raising transformers, the three-phase transmission circuit, the three sub-station lower transformers, and the rotary converter which supplies direct current to the third-rail contact system.

305 Fig. 33, illustrating the three-phase system, is similar to Fig. 32 up to the point where the power passes the sub-station transformers. Power is then delivered directly to the contact system, consisting of two overhead trolley wires, shown suspended from supporting cables in accordance with the commonly used catenary construction.

306 Fig. 34, presenting the single-phase system, has a similarity to the preceding sketch of the three-phase system, Fig. 33, and may be derived from it by simplifying its several elements. Single transformers instead of groups of three are found in the power house and sub-station. The transmission has two wires instead of three and there is but one trolley wire instead of two.

307 Fig. 35 shows the single-phase system where the distances are moderate and the generator can supply current directly to the trolley wire at 11,000 volts, thereby eliminating the high-tension transmission circuit and the sub-stations. This is the method employed in the single-phase installation on the New Haven system.

DIAGRAMS OF TRANSMISSION CIRCUITS AND SUB-STATIONS

308 Fig. 36 shows the arrangement of transmission lines and contact circuits and the relative number and location of sub-stations for each of the three systems.

309 The direct-current sketch, Fig. 36, shows the three-phase transmission line running from the power house to the sub-stations, which contain step-down transformers and rotary converters for changing the high-potential alternating current to low-potential direct current. It also shows the third rail supplemented by an auxiliary conductor or feeder. The track serves for the return circuit.

310 In a certain typical case it was found that the sub-stations should be approximately eight miles apart for a pressure of 600 volts in the direct-current system. If direct current were used at a pressure of 1200 volts, half of the sub-stations could be omitted.

311 The distances above mentioned are found to be proper for a particular case and the diagram is intended simply to show approximately the relative number of sub-stations required in the several systems. The actual distances in other cases may be more or less than those given. In the several systems employing a transmission line the distance may obviously be extended to include a greater number of sub-stations than are shown.

312 The three-phase sketch, Fig. 36, shows the three-phase transmission line and sub-stations containing transformers only, for reducing the high-potential alternating current to low-potential alternating current for use on the double overhead trolley system with track return. The sub-stations are spaced the same distance apart as those in the direct-current system. This arrangement of sub-stations is for 3300 volts on the trolley. With 6600 volts on the trolley, half of the sub-stations would be omitted.

313 The larger single-phase sketch, Fig. 36, shows a single-phase transmission line running to sub-stations containing transformers only, to reduce the high-potential alternating current of transmission to a suitable potential. 11,000 volts, for use on the single overhead trolley with track return.

314 The smaller single-phase sketch shows a single-phase line which is not too long to prevent the entire system from being fed directly from the generators without the intervention of transmission line or transformers between the generators and the trolley circuit. This sketch shows the method employed on the New Haven system.

315 In thickly populated districts congested with traffic, the generating stations, of which there should be not less than two in order to minimize interruptions to traffic, should probably be located at junction points or places demanding the greatest power and at distances not exceeding thirty or forty miles. With such a disposition of power houses, the overhead trolley wires will usually be sufficient for the supply of current. In like manner, where the traffic is not so heavy, the power houses can be placed at greater distances, bearing in mind, however, that the increase in traffic may subsequently demand intermediate power houses or sub-stations. In cases where power stations are long distances apart, the single trolley wire should probably be supplemented by an additional circuit in order to guard against interruptions due to defect in the trolley wire, and to give a sufficient supply of power for any contingency.

COMPARATIVE LOSSES, SHOWN IN FIG. 37

316 Fig. 37 shows the comparative losses between the generators and the locomotives for each of the three systems, based on a class of service where the input to the locomotives by the several systems is practically the same.

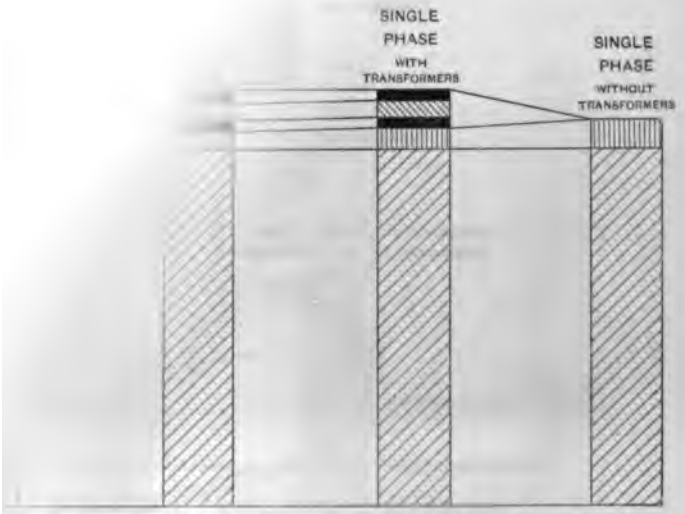
317 As some kinds of service render one type of motor with its auxiliary apparatus and control more efficient, while under other conditions it may be less efficient, this variable element has been eliminated by assuming the same power delivered to each locomotive as a basis for a general comparison of the transmission losses.

318 The total height of each column in the diagram indicates the total power delivered by the power house in the system designated. The height of the long portion at the lower part of each column indicates the amount of power which reaches the locomotive.

Three Phase, High Tension Transmission Line
Rotary Transformer
Sub-Station, Lowering Transformers
Rotary Converter
Third Rail
Overhead Trolley
Track
SINGLE PHASE
Power Stations, not requiring Rotaries.

...resented by the
... transmission
... (comprising

...ers appear only
... shows the losses
...mission line and
...s the trolley wires
...mission line or trans-
... locomotives is relatively



...ing Comparative Losses Between Power House and Locomotives

...with that in any of the other systems. This is the condition ..., New Haven & Hartford Railroad, where the power house is ...0 miles from one end of the line.

COMPARATIVE FIRST COSTS, SHOWN IN FIG. 37

... shows the comparative estimates prepared a few months ago of ... particular case for electrification by the direct-current system ...gle-phase system. In the preparation of these estimates the three-...as not called for and as no estimate covering it has been prepared, ...ed in the present comparison. The estimates cover a single track ...long involving both freight and passenger traffic in both through ...ce and include twenty locomotives.

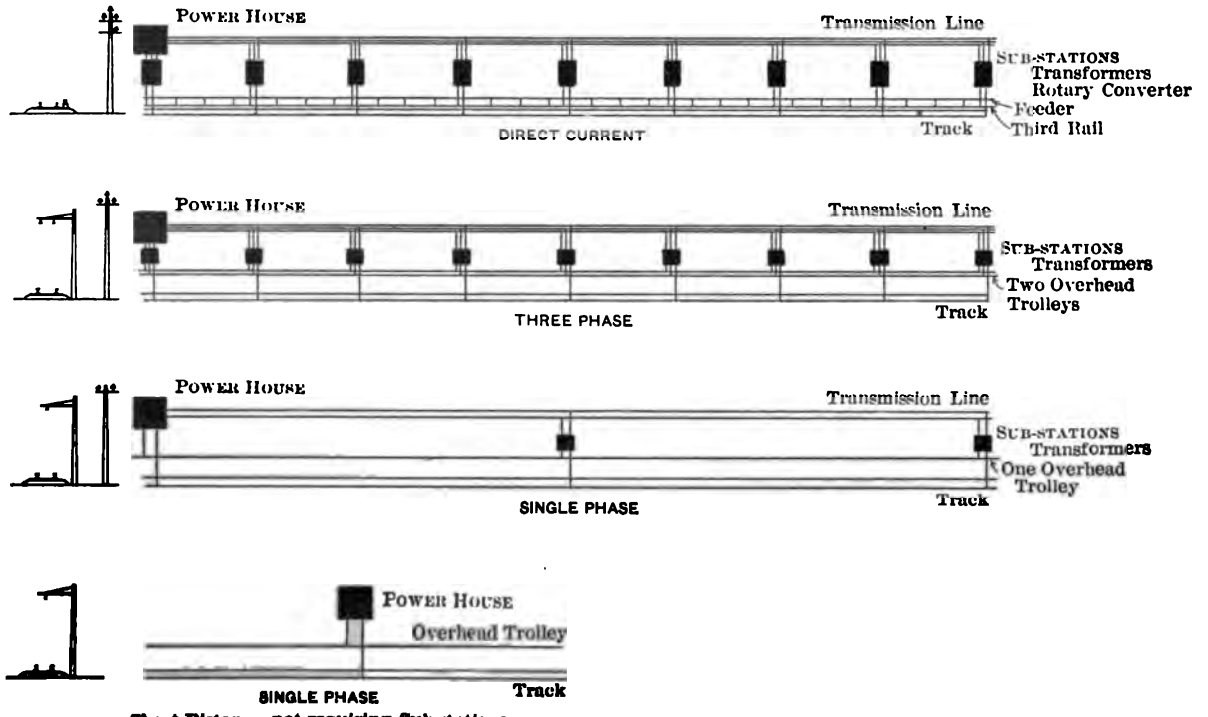
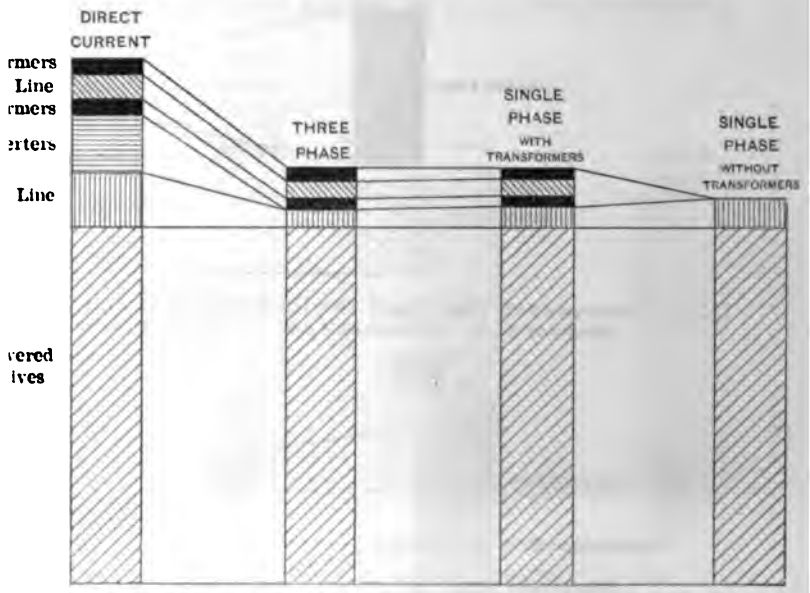


FIG. 36 ELECTRIC RAILWAY SYSTEMS. DIAGRAMS SHOWING TRANSMISSION CIRCUITS, SUB-STATIONS AND CONTACT CIRCUITS BETWEEN POWER HOUSE AND LOCOMOTIVES. CORRESPONDING TO SECTIONS IN FIGS. 32 TO 35

The loss between power station and the locomotives is represented by the aded areas. The respective losses in raising transformers, transmission ering transformers, rotary converters and the contact line (comprising r third rail with track return) are segregated.

It will be noted that the large losses in the rotary converters appear only irect-current system. The larger single-phase column shows the losses ie distances are such that it is necessary to use a transmission line and ners. The smaller single-phase column represents the trolley wires d to the generators without any intervening transmission line or trans- The loss of power between power house and locomotives is relatively



37 Showing Comparative Losses Between Power House and Locomotives

compared with that in any of the other systems. This is the condition lew York, New Haven & Hartford Railroad, where the power house is nearly 20 miles from one end of the line.

COMPARATIVE FIRST COSTS, SHOWN IN FIG. 37

Fig. 37 shows the comparative estimates prepared a few months ago of t in a particular case for electrification by the direct-current system he single-phase system. In the preparation of these estimates the three- stem was not called for and as no estimate covering it has been prepared, included in the present comparison. The estimates cover a single track miles long involving both freight and passenger traffic in both through l service and include twenty locomotives.

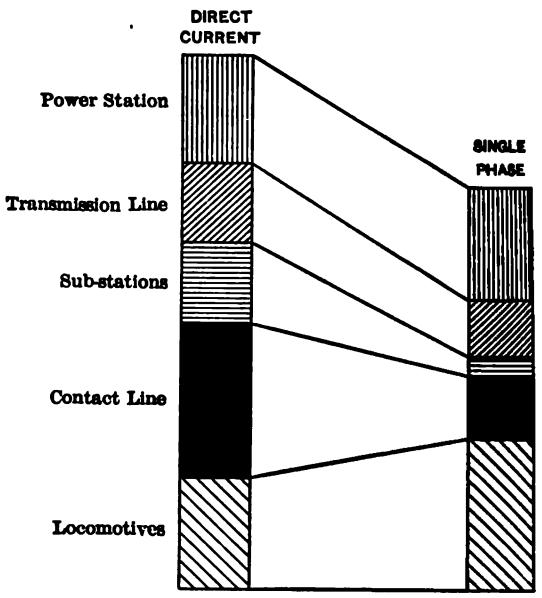


FIG. 38 COMPARATIVE FIRST COSTS FOR DIRECT-CURRENT AND SINGLE-PHASE SYSTEMS IN A PARTICULAR CASE OF 100-MILE SERVICE

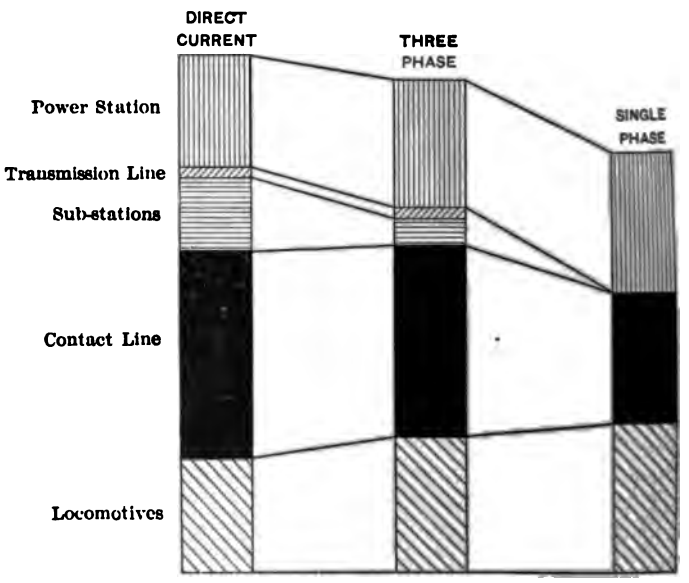
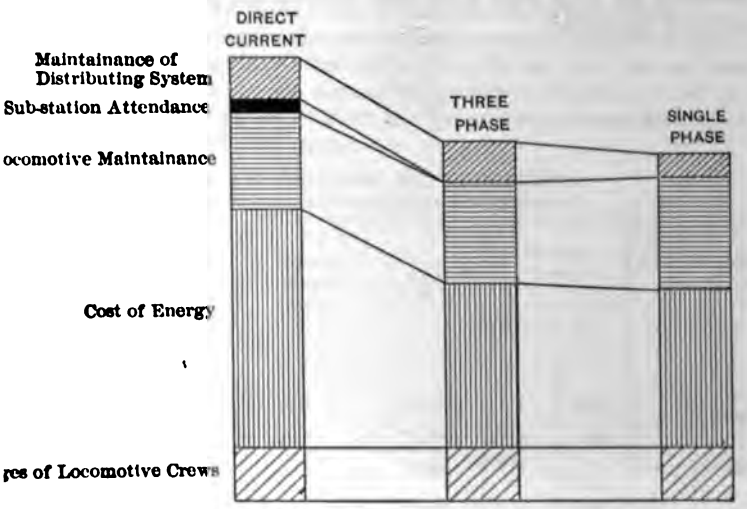


FIG. 39. COMPARATIVE FIRST COSTS IN THE DIFFERENT SYSTEMS FOR A SPECIAL CASE OF PUBBER SERVICE

The costs for power station include only the machinery and building and t include cost of hydraulic development. It will be noted that the considerless cost of the single-phase system in this case is due largely to the lower of contact line and sub-stations.

COMPARATIVE FIRST COSTS, SHOWN IN FIG. 39

Fig. 39 shows the comparative estimates of first cost for the three systems usher service on mountain grades in a particular case involving the use of e locomotives. The total length of line is 32 miles, part of which is single , part double track and part three tracks. In addition to the main line is a large yard to be electrified, there being a total of 90 miles of single track. location of the power station was fixed by non-electrical considerations.



G. 40 COMPARATIVE OPERATING COSTS IN THE DIFFERENT SYSTEMS IN A SPECIAL CASE OF PUSHER SERVICE

listances were such that sub-stations were required when either direct current ree-phase current was assumed, but the entire system could be fed direct the generators if single-phase current was used.

It will be noted that in this case the omission of sub-stations and transon effects a very considerable saving in favor of single-phase as well as the large saving in cost of contact line effected by the use of this system. The of the part of the system between the power house and the locomotives in irect-current system is nearly equal to the cost of both power house and notives. On the other hand, the cost of the single-phase contact line, the intervening element between the power house and the locomotives, is an one-half of the cost of the direct-current transmission and contact system.

COMPARATIVE OPERATING COSTS, SHOWN IN FIG. 40

Fig. 40 shows comparative operating costs for the three systems for the r service outlined in the preceding diagram of first costs. It should be noted

that these costs do not include fixed charges. If fixed charges were included difference in operating costs in favor of the single-phase system would be m more marked.

326 In connection with this diagram it should be noted that sub-sta attendance is required for the direct current system only. The reason for the th phase and single-phase systems being so nearly on a par is that this case i ideal one for the application of the three-phase system since it involves const speed operation under constant-load conditions. It is notable, however, that under these conditions the single-phase system shows somewhat lower oper costs than the three-phase system.

327 The high operating cost with the direct-current system is seen to b largely to the greater amount of power required for operation by this syste account of the large losses which occur between the power house and the motive in this system.

APPENDIX No. 4

ELECTRIFIED STEAM ROADS AND ELECTRIC ROADS FOR TRUNK LINE SERVICE

The accompanying tables give data upon many of the important railroads in which electricity is used in heavy railway service. Only such data are included which are conveniently available and such omissions or inaccuracies as may occur will not detract materially from the forceful presentation of the extent and character of the use which is now being made of electricity in railway service.

The horsepower ratings of the various motor cars and locomotives are in general the nominal ratings for a short period, usually one hour, but as these ratings have been adapted in some cases to the particular service in which the cars are to operate they cannot be taken as a basis for an accurate comparison of the capacities of different equipments.

TABLE 26 SINGLE-PHASE ELECTRIFICATION
ON STEAM RAILWAYS AND IN TRUNK LINE SERVICE

Road	Miles of Line	Miles of Single Track	Line Voltage	Motor Cars		Locomotives	
				No.	h.p.	No.	h.p.
[illegible] H. R.R.R. [illegible]	21	100	11,000	4	600	41 2	1400 1600
[illegible]aan Br.	8	8	11,000	2	500		
[illegible]k R.R.	3.5	12	3,300	...	...	6	900
[illegible]r Div.	34	34	11,000	6	400	...	...
[illegible]outhern Ry. Interurban	46	46	11,000	8	500	...	...
[illegible]k Annapolis [illegible]e	25	30	6,600	12	400	...	...
[illegible]ate Ry.	7	7	3,300 20,000	2	240	1	300
[illegible]y., England	8.5	17	6,600	1 2	300 360	...	...
[illegible]ate Rys.	16.5	31	6,600	20 42 54	250 400 345	1	1500
[illegible]righton & [illegible]ast Ry.	8.6	17.2	6,000	16	460	...	...
[illegible]-Haag-[illegible]ngen.	20.5	46.5	10,000	19	360	...	...
[illegible]Inland.	129	129	6,600	28	400	6 5	500 720
[illegible]f France..	75	...	12,000	30	500	2	1600

that these costs do not include fixed charges. If fixed charges were included t difference in operating costs in favor of the single-phase system would be mu more marked.

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k Annapolis e.....	25	30	6,600	12	400	...	....
ate Ry.....	7	7	3,300 20,000	2	240	1	300
y., England	8.5	17	6,600	1 2	300 360	...	....
ate Rys....	16.5	31	6,600	20 42 54	250 400 345	1	1500
Brighton & ast Ry.....	8.6	17.2	6,000	16	460	...	....
-Haag- ngen.....	20.5	46.5	10,000	19	360	...	....
Inland.....	129	129	6,600	28	400	6 5	500 720
f France..	75	...	12,000	30	500	2	1600

TABLE 27 CONTINUOUS-CURRENT ELECTRIFICATION

ON STEAM RAILWAYS AND IN TRUNK LINE SERVICE

Road	Miles of Line	Miles of Single Track	Line Voltage	Motor Cars		Locomotives	
				No.	h.p.	No.	h.p.
N. Y. C. R.R.	33	132	650	137	400	47	[illegible]
Pennsylvania R.R.	20	75	650	180	400	24	[illegible]
West Shore R.R.	44	106	650	20	360	...	....
Long Island RR.	42	125	650	137	400	2	[illegible]
West Jersey & Seashore R.R.	75	150	650	68	400	...	....
B. & O. R.R.	3.7	7.4	600	...	...	2.5 5	[illegible]
Northeastern Railway.	37	...	600	...	300	2	[illegible]
Mersey Tunnel	4.8	...	600	24	400	...	....
Lancashire & Yorkshire Railway	18	60	600	...	600	...	....
Great Western Ry.	5	...	600	...	600	...	....
Metropolitan Railway.	...	67	600	56	600	10	[illegible]

TABLE 28 CAR EQUIPMENT OF SUBWAY AND ELEVATED SYSTEMS IN AMERICAN CITIES

THE DIRECT-CURRENT THIRD-RAIL SYSTEM AT APPROXIMATELY 600 VOLTS IS USED IN ALL CASES

Road	Miles of Single Track	Motor Cars	
		No.	h.p.
Boston Elevated Railway	19	219	[illegible]
Brooklyn Rapid Transit	71	558 101	[illegible]
Interborough Rapid Transit (New York)	190	969 764	[illegible]
Hudson & Manhattan (New York)	12	140	[illegible]
Chicago & Oak Park	19.4	66	[illegible]
Metropolitan West Side (Chicago)	51.1	15 210	[illegible]
Northwestern Elevated (Chicago)	25.5	20 128	[illegible]
Southside Elevated (Chicago)	36.5	150 70 150	[illegible]
Philadelphia Rapid Transit	11	100	[illegible]

TABLE 29 THREE-PHASE ELECTRIFICATION

ON STEAM RAILWAYS AND IN TRUNK LINE SERVICE

load	Miles of Line	Miles of Single Track	Line Voltage	Motor Cars		Locomotives	
				No.	h.p.	No.	h.p.
hern R.R. Tunnel.....	4	6	6600	..	...	4	1900
te Railways.							
a Railway ..	66	...	3000	10	400	2 7	800 1500
ailway.....	12.4	37.3	3000	..	..	20	2000
is Tunnel...	4.4	...	3000	..	..	10	2000
Ceva.....	...	...	3000	..	..	10	2000
ral Railways Tunnel....	13.7	14.3	3000	..	..	2 2	1100 1300
ta Fé(Spain)	13.1	14 4	5500	..	..	5	320

APPENDIX No. 5

THE EARLY HISTORY OF SINGLE-PHASE RAILWAY MOTORS

330 In Par. 230 brief mention was made of two single-phase motors of 10 h.p. built in 1892 by the Westinghouse company for determining the possibilities of using alternating current for traction work. These motors were designed for 2000 alternations per minute and about 200 volts. They were of the series type, with commutators, and had a relatively large number of poles. They were mounted

FIG. 41 THE FIRST SINGLE-PHASE ELECTRIC CAR. DESIGNED IN 1892 AND EQUIPPED WITH TWO SINGLE-PHASE SERIES MOTORS

upon a car and tested on a short piece of track with some very short curves and rather steep grades. The car is shown in the accompanying illustration, Fig. 41. The current was supplied from a conductor placed intermediate between the rails. The capacity of the engine and generator used for these tests was insufficient for the service, and the voltage drop in the rails was excessive. The test showed that the motors would run the car, although the current available was hardly

ient for operating the car on the curves and grades. A transformer on the erved to transform from a few hundred volts on the supply circuit to that red for the motor. There were several taps on this transformer, and by s of several single-pole switches, the voltage could be varied. Several encies lower than that for which the motors were designed were employed sting the motors.

Almost the entire effort in railway work at that time was concentrated ectric cars for city service. While the single-phase system gave promise of in advantages for this service, it was found that there were disadvantages, cularly in the large losses in the conductors for supplying the current, which red the single-phase system much less adapted to this service than the direct- nt system.

It was recognized that the single-phase system would be ideal for loco- ve operation, but as no projects of this sort were then in view, no immediate was done in building large motors of this type.

Some seven or eight years later, the enlarging field of railway operation howing the imperative need of some practical method by which high tension be used on the trolley wire in order to minimize the cost of supply circuits. ermore, the accrued experience and greater knowledge in the methods of ning alternating-current motors opened the opportunity for the development perfection of the single-phase system.

Motors of 100 h.p. were designed, built and tested on an experimental . The results of this work and the importance of the single-phase system lway operation were presented in a paper by Mr. B. G. Lamme before the ican Institute of Electrical Engineers in September 1902. This paper ened widespread interest and was followed by the active development of -phase apparatus by a number of manufacturing companies, both in America n Europe. There are now about 60 single-phase railways in operation.

[SCUSSION ON RAILWAY ELECTRIFICATION

[OHN A. F. ASPINALL[1] said that he wished to express their very at regret that Mr. Westinghouse, President of The American iety of Mechanical Engineers, was unable, as he had intended, to present to read his own paper; but he had written a special letter ing that that would be done for him by Mr. Scott. Each of the ers to be read dealt with the subject in a different way, but ry one of them was interesting. Mr. Westinghouse's paper aded for a careful consideration of the system which ought to be opted to enable railways which were electrified to interchange ir trains, and urged that the subject should be considered on an linary commercial basis.

The whole question of the commercial success of electric railways s dealt with in a very prominent manner by Mr. Pomeroy, who, the end of his paper (Par. 208), pointed out the necessity for com- rcial considerations, and said: "The idea is all too prevalent with e public, and even with some of the bodies that have been given al power of supervision over railway companies, that any expendi- re which can be forced upon the railway companies is just so much in for the public. Never was there a more absolute fallacy. In e long run, the cost of every bit of railway improvement must be id for by those who buy tickets and ship freight. Economy in e administration of our railways is just as important in the interest the general public as if the railways were actually under govern- nt ownership." He read that passage because it seemed to him at it was the direction in which it was necessary to look in order at electric railways might be successful.

HARLES F. SCOTT,[2] after reading Mr. Westinghouse's paper, d that just before he departed from America Mr. Westinghouse d to him that he would like to have some one present at the

[1] Pres. I. Mech. E., Genl. Mgr., Lancashire & Yorkshire Ry., Hunt's Bank, nchester, Eng.

[2] Past-President, A.I.E.E.; Consulting Eng., Westinghouse Elec. & Mfg. Co., tsburg, Pa.

Presented at the meeting of THE AMERICAN SOCIETY OF MECHANICAL GINEERS with THE INSTITUTION OF MECHANICAL ENGINEERS, London, gland, July 1910.

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meeting who appreciated his purpose and motive in preparing the paper. He said he could illustrate the point by giving an instance. Several years ago, when the question of the compulsory electrification of railways in tunnels and terminals was before the New York legislature, and about the time that certain tunnel disasters took place both in America and in Europe, Mr. Westinghouse publicly advocated the use of steel cars for passenger service in tunnels. The matter was taken up and generally discussed, and he was severely criticized in some quarters for making the suggestion; he, however, adhered to the suggestion he had made, and steel passenger cars were now becoming the standard for that type of service in America. The Pennsylvania Railroad Company had adopted them, and he believed it was the intention of that company that all cars which entered the new tunnel and terminal at New York City, even the cars which went west to Pittsburg and Chicago, both coaches and sleepers, should be of steel, and many of those cars were now running. Mr. Westinghouse added that at the present time he was endeavoring to give his best thought from the railway standpoint to the question of electrification, in order that he might do a future service to railways.

H. F. PARSHALL,[1] in opening the discussion, thought the Institutions were to be congratulated on the character of the papers and on the eminence of their authors. Mr. Westinghouse's name was known throughout the world as a pioneer in electric traction and in traction generally. Mr. Potter's name was not so well known, principally because he was the chief engineer of a great organization, but it might be said that, considering Mr. Potter's connection with traction affairs during the whole development of the electrical apparatus of the General Electrical Company, he was probably the first authority in the world so far as the details of electric traction installation were concerned. The other authors were well known, and he need not comment upon their merits. One point which came out last, which showed the vastly different point of view of American traction compared with English traction, if it could be justified, was, that in an electric traction installation in America the cost of transmission was the controlling factor. That certainly was not so in this country, where there was an institution called the Board of Trade, which insisted upon the most expensive form of transmission system that could be thought of. Only seven-volts drop in the earth return was

[1] Mem.Am.Soc.M.E.

allowed, which meant numerous sub-stations of large capacity. It would hardly be credited by American engineers that in a line like the Central London Railway, of which he was the consulting engineer, which was only six miles long, there should be five sub-stations which had a net capacity of 9000 kw. for 32 seven-car trains. It was impossible for that railway, under all conditions of working, to comply with the requirements of the Board of Trade and of the Postmaster General, except by that arrangement. In addition to the sub-station arrangements there was a storage battery system which would work the entire train service for a short time. The arrangements were most elaborate, more elaborate than would be required for any surface road, because it was necessary to get the passengers out of the tunnel in case of a general failure. He thought it would be conceded that such a transmission system was as elaborate as it possibly could be. However, taking total capital charges at the rate of 5 per cent, and the energy lost in the system, the total cost of the transmission was 15 per cent of the total; the cost of the maintenance, including the corresponding cost for the operation of the rolling stock was something like 45 per cent, and the cost for the balance, the power house, and so on, was something like 40 per cent of the total motive-power charge in an elaborate traction system of that description; that is, the cost of maintaining and operating the rolling stock was three times that of the transmission cost.

In America, where the sub-stations were further apart and where there was no restriction in respect to the use of the earth return, the transmission system must be a great deal cheaper, so that he could not readily accept the statement of Mr. Westinghouse that in a traction system the controlling feature was the transmission system. Again, taking the figures of 40 or 45 per cent for rolling stock, including the maintenance, and 5 per cent on the capital, the transmission system at 15 per cent on the same basis, and applying the figures which Mr. Hobart had given, which were representative not only of the installations in this country, but of American installations, it would be found that the difference in capital charges as between direct-current and alternating-current, so far as rolling stock itself was concerned, would more than wipe out the whole cost of the transmission system. It would leave a negative balance; the alternating-current system would have to bring with it a premium to the user for the installation.

Then, again, there must be primarily considered some transmission system on an alternating-current single-phase railway when

generally extended. Supposing that they had to transmit the same amount of power over the same distance, one single-phase and the other three-phase, with unity power factor one-third more copper would be required for the single-phase than for the three-phase system. In the single-phase installation the power factor was less than unity. In the three-phase, by the use of rotary converters it might average approximately unity. The best figure that was given him in America by alternating-current advocates was 75 per cent power factor in a general single-phase system. Carrying those two factors into a general calculation, and allowing 10 per cent loss in the rotary converter, the conclusion reached was that the cost of a high-power transmission line for a single-phase system was 60 per cent greater than for a direct-current system; the calculation of which was based on an equal current density in the copper. If it was taken for equal energy loss, the cost of copper to convey the same amount of energy would, owing to the difference in the transmission, and in the power factor, be twice as much for the single-phase system as for a three-phase system.

He had recently been to America, and through the courtesy of Mr. Murray had been over the New Haven system. He had also been over the New York Central system. One fact which stood out most prominently was that each system was competent to deal with dense terminal traffic in a way that steam traffic could not deal with it. With regard to systems, he did not think the New York Central could be compared with the New Haven, at least from a British point of view. The New Haven system could not be operated in England under the Board of Trade regulations; all the safeguards that had to be provided in this country had been most studiously left out of the New Haven system. He did not wish to criticise the system unfairly or in detail; Mr. Murray was certainly most enthusiastic and most courteous, but was considering the problem as a trunk-line question only. One point which came out very strongly, and on which he found that most American engineers were unanimous, was that for suburban work or interurban work, or practically any service in which the motor car was necessary, the single-phase was hopelessly out of it. In the case of trunk-line work, where the locomotive would be the main factor, a great deal remained to be said, but so far as immediate application in England was concerned, the single-phase system, in the light of American experience, was suitable only to a class of haulage that was not likely soon to become electrified.

There were undoubtedly a great many railways in this country that

would profit largely in their terminal arrangements by electrification. Some of the great railways in London were experiencing the severest difficulty at the present time in handling their terminal traffic. The controlling factor of such a system would be the capital cost. Where acceleration in dense terminal traffic was the ruling condition, a single-phase system was vastly more expensive in its first cost, it would not give the same acceleration, and it must be expensive to operate. He did not think he would add to the value of the discussion by going into all the figures mentioned in the papers. Figures could be presented from different points of view, and could not be intelligently discussed unless all those different points of view were known to those who were discussing them.

J. DALZIEL[1] said that in both the English papers before the meeting it was asserted that main-line electrification was commercially impracticable, and that suburban working might therefore be dealt with quite aside from any main-line considerations. While he did not agree with that view, he considered it more reasonable than advocating separate consideration of every case. That course, to his mind, spelled chaos. He believed that main line electric working in England was not only commercially but comparatively imminent, and if that was so it was unquestionable that, other things being equal, to design to fit in with those future conditions was more important than anything else in scheming any electrifications, and that therefore the finding of a generally applicable all-round system was the most important electric traction problem of today. He took up that position in his joint paper[2] to the Institution of Civil Engineers last winter, and followed it out to show by the results of tests that the single-phase system was burdened with few if any of the disabilities attributed to it, more particularly for suburban work, and that, other things thus being equal, it emerged as the desired generally applicable system. According to his paper before the meeting, that was Mr. Westinghouse's opinion, and it also represented apparently that of the continental engineers, whose adoption of single-phase, particularly in Germany, for heavy working was almost universal. A similar conclusion was reached within the last few weeks at the conference of the International Railway Congress. Even granting for the moment that single-phase had disadvantages in suburban

[1] Chief Mechanical Engineer's Office, Midland Railway, Derby, England.
[2] Proc. Inst. C. E., 1909, vol. 179, p. 47.

work, he did not see how electrification could be regarded as a narrow question of separate sections and districts. Leaving aside detail, into which he had entered elsewhere, the same policy necessarily evolved to meet the continuous growth of traffic that had led to doublings, widenings, and regradings, pointed directly to electrification, and he failed to see how, without information as to the existing railway conditions, it was possible for any correct judgment to be formed as to the actual demand for increased capacity. It was clear that, with all the doublings and widenings that had taken place, there must be at the present time lines which were approaching their maximum capacity, and where expensive methods, such as double-heading, banking, and so on, were required; and the necessary added capacity of those lines could be obtained far more cheaply by electrification than by doubling or regrading. For example, though he made no allegation as to congestion on the lines in question, and spoke not at all for the company with which he was connected, the disparity between the relative costs of electrification and of regrading alone, without doubling, on the Derby-Manchester and Sheffield-Manchester sections of the Midland main line would clearly be overwhelmingly in favor of the electrical alternative. It was true there were no water powers in this country, but there was coal of cheaper quality than could be burned on a locomotive, and, in fact, electrification schemes on those very lines were in progress in Germany, while the heavy, continuous and mixed traffic, the large amount of shunting and terminal work, and the congestion and heavy grades of many sections and branches were factors favoring electric methods here more than anywhere. To ignore main-line work, then, would be to take a very serious risk of incurring future complications and retarding natural development, and that being so, single-phase in suburban work must have drawbacks very pronounced indeed to justify its being discarded.

The English papers before the meeting were adverse to single-phase, but the allegations made earlier in its history, of inferior acceleration and higher power consumption for similar schedules, had disappeared. There remained adverse weight and cost comparisons and unreliability. Mr. Potter's reports as to unreliability probably resulted, to some extent, from the double-current working so largely used in America, which, by the complications it introduced, and which it was hoped would be avoided in this country, undoubtedly must reduce reliability as well as increase both cost and weight. Single-phase apparatus being new, progress in knowl-

edge and design would assuredly reduce both weight and cost. In respect to reliability, and in particular to Mr. Carter's remarks as to the use of forced draft, he would like to mention that the Midland's Westinghouse single-phase equipment at Heysham had had only four breakdowns in the two and a half years of its service, and those, being caused by failures respectively of a lightning arrester, a badly made high-tension joint, a circuit breaker trip coil, and a motor armature, could hardly be attributed either particularly to the fact of the apparatus being single-phase or in any way to forced draft being in use.

With regard to efficiency, the lower single-phase efficiency was counterbalanced by the single-phase motor characteristic being better suited to heavy schedule suburban service, because of its better sustained acceleration, a feature which might be accentuated by overvoltage tappings, and which increased coasting and decreased brake losses. In fact, cases in which the actual power-station output or purchased energy for the railway were so appreciably greater with single-phase as to justify its being rejected if there was any possibility whatever of long distance extension were, notwithstanding greater equipment and train weights, practically non-existent, and in most cases single-phase should go in on its merits. Taking one example only, Mr. Aspinall's Liverpool-Southport trains had a consumption of 96 watt-hr. per ton-mi. On a similar schedule the Midland Heysham train consumed on test 88 high-tension watt-hr. per ton-mi. with a very light train. With trains of similar accommodation the respective power-station outputs would be as 1.25 to 1 direct-current to single-phase, the latter being 3.8 per cent the heavier, making no allowance for better working of the longer train. That schedule could be maintained by the alternating-current train continuously. He would like to say that Mr. Carter's direct-current efficiency on Fig. 5 was 93½ per cent overall, and they must be specially good motors. He would also say that Mr. Carter's time-speed curves in Fig. 5 were not quite fair in this respect to single-phase, as the respective gear ratios were such that the free running speeds of the train shown were higher in the alternating-current than in the direct-current case, notwithstanding that the alternating-current train was heavier per motor. He would not follow Mr. Carter's anti-forced draft remarks, as forced draft was being increasingly adopted, and involved no difficulties not easily got over. Mr. Carter would have to take things, including single-phase motors, as they were.

What he had to say as to Mr. Hobart's paper hinged largely on

his Table 3. In the first place, the Heysham trains were
primarily designed for the service analyzed by Mr. Hobart. T
took occasional loadings much in excess of those given, the Mid
working time-table permissible loads being 215 tons between H
sham and Morecambe, and from Morecambe to Lancaster, and
tons from Lancaster to Morecambe. On busy days in summer the
took four-coach trains for many hours together as rapidly as t
trains could be got in and out of the stations, and that service
principally between Lancaster and Morecambe, which was a sh
distance and a higher speed schedule, being less restricted by
restrictions than that in Table 3. What those coaches were
capable of doing might be typified by the 30-mi. per hr. 1.32-mile s
with 88 watt-hr. per ton-mi. consumption already mentioned.
ing with those the revised Siemens equipment weight, he had
up another analysis of the Heysham train bringing out the
horsepower output per ton of electrical equipment at 8.8
however, Mr. Hobart wished to make a comparison on actual w
and on the schedule he had worked on, a fair comparison would
been made on the Westinghouse car, which worked on that sc
as the others did, and the equipment of which weighed only 1
On that basis the single-phase horsepower output per ton wo
7.2. That, however, by no means ended his criticism. As T
was a comparison really of continuous output, and still re
one in which a forced-draft motor made a worse showing
naturally ventilated one, it was evident there was somethi
wrong. As a matter of fact, there must be a miscalculation
ton-mile consumption given for the Piccadilly train. By a
simple calculations which he had put in (Table 30), and which we
to Mr. Hobart's criticism, it was easy to show that on that out
mean current input per motor was of the order of 95 amp
that the root mean square current per motor could not be le
about 150 to 200 amperes, or the unheard-of figure for a na
ventilated motor of a half to two-thirds of the one-hour rating
Hobart in his book gave the root mean square current of a na
ventilated traction motor at about a quarter of the one-hour
which would give for the Piccadilly motors a root mean squa
rent of about 75 amperes. The Piccadilly consumption, an
given by Mr. Hobart for the same schedule in his Table 7 w
tirely in disagreement with the consumption figures for like
ules in Mr. Hobart's book, Electric Railway Engineerin
Diagrams 90 and 94 to 96 (pp. 77 to 80) of that book, practica

very schedule was given as requiring a consumption of only 56 watt-hr. per ton-mi. with 32 sec. coasting, up to 72.8 with no coasting at all; that was the absolute maximum, the consumption being reduced on a track graded for acceleration and retardation to 30.7 watt-hr. The Piccadilly line was described in the Tramway and Railway World as graded, but he questioned if that grading was extensive. He found by observation that coasting between the shorter distance stations averaged about 38 sec., which would therefore make the working of the line correspond, even if level, to certainly no more than the above-mentioned 56 watt hr. per ton-mi. Giving Mr. Hobart for tunnel train resistance, which, according to a footnote of

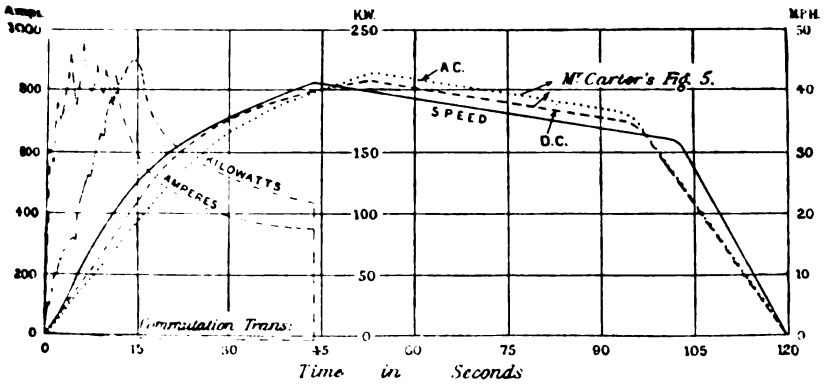

FIG. 42 SIEMENS CAR, HEYSHAM
21.5 Tons per Motor. Gear Ratio, 3.7 to 1. Wheels 40 in.

his paper should not have much effect, an increased allowance up to 63 watt-hr. per ton-mi., and revising his figures accordingly, his specified figure for output per ton of the Piccadilly equipment became 7.4 against the specific output of the Heysham train, already mentioned, of 8.83. Such a result was only to be expected in consideration of forced draft being in use on the latter. That corresponded to a root mean square current on the Piccadilly train of about 120 amperes, which was quite high enough. He could not hazard a conjecture as to where Mr. Hobart's error had been made, unless he had divided the total ton-miles of the railway into the total watt-hours as supplied to it. In that case he must have included all the current supplied to the lifts, heating, ventilation, lighting, etc., which he was hardly entitled to put to the credit of his motor horse-power output capacity.

In further reference to the subject of gear ratios, the free runnin speed of a train, that is, the speed at which acceleration practicall ceased, was of considerable importance. Its being too high practicall meant that part of the available power of the motors was thrown awa owing to their being run at a lower overall speed, and inordinate pus ing up of the root mean square current also results. Had the alte nating-current gear ratio of Mr. Carter's Fig. 5 been more suitabl the alternating-current acceleration would have been improved, a the power consumption lessened, the margin for making up tin remaining about the same. For some reason, however, the spe time curve of Fig. 5 did not represent anything like the best that alternating-current train of the weight per motor given was capab

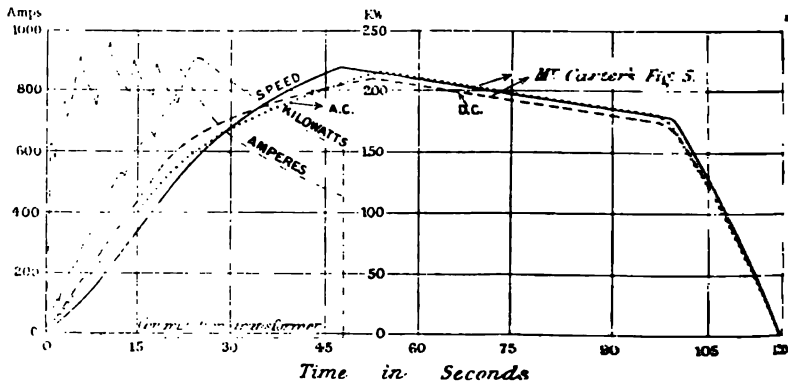

FIG. 43 EXPERIMENTAL RUNS, HEYSHAM

Representative Train for 26 Mi. per Hr. Schedule. Weight, 43 Tons Norm Gear. 21.5 Tons per Motor. Gear Ratio, 2.93 to 1. Wheels, 43½ in.

of, and he (Mr. Dalziel) appended curves (Figs. 42 and 43), base on tests made by himself. comparing Fig. 5 curves with two alte nating-current trains of 21 tons per motor, one geared for a highe and one for the same free running speed as the direct-current trai

As regards Fig. 5 direct-current motor efficiency, it should b explained that the efficiency of 93½ per cent was obtained by totallin the respective curves of output and losses on Fig. 5, and as the figu of 93½ per cent so obtained was not the free running but the efficienc overall from start to stop, it was a very high figure.

Touching on the question of the Piccadilly train consumptions an on the 30 per cent allowed for passenger weights and shunting co sumption, he desired to make it clear that in the train he had use for comparison, weight of passengers was allowed for. In respe to making a consumption allowance for shunting, shunting was n

a timeless operation nor one taking place concurrently with schedule working, as it would require to be to make it legitimate to credit shunting consumption to the motors as specific output during schedule service. If shunting took place, it necessarily involved lie-overs and standing periods, and further was obviously not itself performed at schedule speeds; it then so reduced schedule speed as obviously to make it entirely incorrect to calculate the specific output of the motors on the basis of train-mile input by schedule speed as was done in Mr. Hobart's tables. The greater the shunting, in fact, the less would be the hourly motor output, whereas on the contrary, Mr. Hobart used shunting consumption to push up his motor output, and so practically claiming that the Picadilly trains did a considerable amount of shunting, and yet simultaneously worked continuously at their schedule speeds.

TABLE 30 MR. HOBART'S TABLE 3 REVISED

	Piccadilly Train	Heysham Train Ordinary Service Westinghouse	Heysham Train 1.32 mile 30 m.p.h. Service
Number of motor coaches	1	1	1
Number of trailer coaches	2	2	.....
Total number of coaches in train	3	3	1
Number of motors	2	2	2
Total number of axles in train	12	12	4
Number of axles driven by motors	2	2	2
Length of train, feet	150	150	60
Weight of train, tons	61	74	43
Schedule speed (a) mi. per hr	16.4	31	30
Distance between stops, mi.	0.45	4	1.32
Energy consumption per ton-mile watt-hr.	63	40	88
Energy per train-mile (b) kw-hr.	3.84	2.96	3.79
Average input per train ($= a \times b$) kw.	63	92	113.5
Average output from motors to axles taking average efficiency of electrical equipment as 70 per cent h.p.	59	86	106
Weight of electrical equipment, tons	8	12	12
Average output per ton of electrical equipment	7.4	7.2	8.83

ANALYSIS OF PERFORMANCE OF PICCADILLY TRAIN

Line voltage, 550 volts

On series for 8 sec. at 150 volts	1 200
On parallel for 7 sec. at 410 volts	2 870
Running of motor curve 20 sec. at 550 volts	11 000
Total for 35 sec.	15 070
Hence mean voltage while taking power	430

Now taking mean input as 93 kw. per train we have 46.5 kw. per motor. Therefore the mean motor current allowing 15 per cent for losses in rheostat equals

$$\frac{46.5}{430} \times 0.85 = 92 \text{ amperes}$$

which will correspond to a R.M.S. current of about 150 to 200 amperes. Now taking mean input as 63 kw. per train we have 31.5 kw. per motor. Therefore the mean motor current allowing 15 per cent for losses in rheostat equals

$$\frac{31.5 \times 0.85}{430} = 62 \text{ amperes}$$

which will correspond to a R.M.S. current of about 90 to 120 amperes.

COMPARISON OF DIRECT-CURRENT AND SINGLE-PHASE TRAINS TO GIVE SAME SEATING CAPACITY AND SCHEDULE AS MR. ASPINALL'S 117-TON TRAIN

MR. ASPINALL'S TRAIN

	Tons	Passengers
2 motor cars with luggage compartment at 46 tons	92	128
1 trailer car	25	66
Total	117	294

Total energy consumption on 1.32 mile 30 mi. per hr. schedule at 96 watt-hr. per ton-mi. equals

$$117 \times 96 = 11.32 \text{ kw-hr.}$$

Now transmission efficiency bus bar to collector shoe as given by Mr. Aspinall equals 81 per cent. Therefore energy output of generating station per train-mile equals

$$\frac{11.23}{0.81} = 13.9 \text{ kw-hr.}$$

SINGLE-PHASE TRAIN FOR ABOVE SERVICE

	Tons	Passengers
2 motor cars with luggage compartment at 40.5 tons	81	128
1 motor car at 40.5 tons	40.5	66
Total	121.5	294

Total energy consumption at 88 watt-hr. per ton-mi. equals

$$121.5 \times 88 = 10.7 \text{ kw-hr.}$$

Transmission efficiency bus bar to collector equals 97 per cent. Therefore the energy output of generating station per train-mile equals

$$\frac{10.7}{0.97} = 11.0 \text{ kw-hr.}$$

Hence the ratio of the direct-current power station output to the alternating-current power station output equals

$$\frac{13.9}{11} = \frac{1.24}{1}$$

The single-phase weight exceeds direct-current weight by 121.5 + 117.0 or 4.5 tons, which equals 3.8 per cent.

SIDNEY STONE[1] said it appeared to him that one very important feature in connection with electric traction had scarcely been touched upon, namely, the wear of the track, which the president had laid very great stress upon in his Presidential Address,[2] and which was referred to in Mr. Westinghouse's opening statement. He had hoped to hear from their American friends something of their experience as to track wear. He believed it was an admitted fact that the wear of the tracks of electric railways in this country was excessive, more particularly on those lines in which the multiple-unit system was used. He believed that on the City & South London Railway, where an electric locomotive was employed, the wear was not so marked; but on the other lines, more particularly on the District Railway, where long trains were used, in which there were two or three motor-coaches, one in the front, one in the rear, and during the rush hours one in the middle, the wear was very noticeable. He had not seen that point touched upon, but it had occurred to him that probably the right point had not been looked at for the purpose of ascertaining the cause.

Before the London & North Western Railway trains were taken off between Earl's Court and the Mansion House, the rails on the adjoining road could be seen much better than from the District trains, and he had been very interested in watching the effect of the wear as far as he could from the carriages. He did not know what it was due to, but about every 40 feet, bright worn spots were visible on the rails. Apparently the bogies were digging into one side of the rail until they met sufficient mechanical resistance to throw them over to the other side. He believed it was a fact that the rails had worn very much in that direction, especially on curves. It had occurred to him that the wear, more particularly on curves, and with the multiple-unit system, was due to the fact that when a train approached a rising gradient or curve, there was increased mechanical resistance due to the up-gradient or rail friction on the curve, as the case might be, and such resistance would be felt first by the leading motor coach. The motor at the rear of the train had not the same resistance to overcome, with the result that it pushed the train up, thus forcing the flanges against the side of the rails. It had the same effect as was noticeable when pushing a train of wagons on a curved siding; when the train was pushed against a dead end

[1] M. I. Mech. E., London, Eng.

[2] Proc. I. Mech. E., 1909, Pt. 2, p. 423.

or other wagons, the wagons in the middle of the train are bul outwards, forcing the wheel flanges against the outer rail, the t dency being to throw the train out of line with the road. He co not help thinking that this had something to do with the exce wear on the side of the rails. With a locomotive the whole of tractive force was exerted at the front of the train, and it was b pulled in a line which conformed to the road. He went so fa to get out a scheme, in collaboration with a friend, to insure t there was always a maximum tractive effort obtained on the f motor in whichever direction the train was traveling. If a multi unit system were used, then it seemed to him it was necessar increase the power on the front motor; in other words, the d bars were kept taut instead of being slack. In that way the c ing up of the train was avoided. He had often noticed a train in the station; probably the front coach was on a curve, and the one was on a comparatively straight road. As soon as the t started, the rear motor car would bump the other carriages up, the result that distortion was produced, and the wheels of the co were forced on to the outer rail.

CHARLES F. SCOTT said the range of the papers which had read indicated that it was necessary to keep in mind the br and variety of conditions which had to be dealt with. It might al be said with regard to railway electrification that there were no ge rules; there were specific cases only. The various elements v entered into a consideration of the subject, which were enume in one of the papers, such as the length of line, the density of t the character of traffic, the gradients and the speeds, were all fa which must be considered. The problem must be taken as a v and not in parts. Consequently, generalizations were very a be quite misleading, if they were based on a specific case. Elect had a way not only of doing the same things that had been done b but often doing them in a better way, and also of introducin methods. That was found to be the case also in industrial ap tions.

The literature of fifteen or twenty years ago with regard t electric motor was very largely a comparison of the relative required and the relative efficiency of transmission by shaftin belting as against motors. However, when motors had been duced, and had demonstrated their capabilities, it was no economy of power but accomplishment which became thei

nerit. The gain in output and in quality which often resulted from what may be termed the indirect advantages of electric drive, were often the most valuable results. Similarly there are indirect advantages in railway electrification, some of which had been touched upon in various papers. It had been brought out that the increased capacity of a railway line at congested points by making unnecessary an increase in track facilities might be the great advantage of electric traction.

New possibilities also arose with regard to railway terminals. A railway with many tracks meant a great breadth; it meant the acquisition of large areas in centers of population where ground was extremely expensive. Electrification permitted of double-decking or treble-decking in tubes of railways, so that the same number of tracks could be built in very much less space than was now employed. The tracks might be built over in the form of warehouses, which would thus utilize much ground which was now practically wasted for other purposes than the actual right of way into the city. It had been suggested that in the ideal railway warehouse, cars could be raised by elevators and shifted into the upper floors of the warehouse, and there directly unloaded without the great cost of trucking. He mentioned these as some of the new advantages which electrical operation might bring about. The differences in terminal methods, tunnel methods and operating methods might become very large factors of advantage in railway electrification.

Reference was made in the papers to the effect of the electric cars or locomotives on the tracks. In this connection he called attention to Table 24 of Mr. Westinghouse's paper, which showed a high center of gravity due to the elevated position of the electric motor in certain locomotives, corresponding to the high center of gravity of the steam locomotives. It would be noticed in that table that three of the locomotives showed motors which were well above the driving axles. In two of them, the third and the last on the page, the motor was mounted up in the cab, the driving being by connecting rods. While that construction had been used on the continent, it was new to America. The locomotives for the Pennsylvania Railroad shown in the middle column had very large motors up in the cab. Those locomotives were, he believed, the largest and most powerful which had ever been made. The fourth locomotive shown, built for the New Haven Railroad, was of interest, as each motor was mounted directly over the axle which it drove by gearing at each end. The last two types of locomotives shown

were made for the New Haven Railroad for a combined passenger and freight service. One of them had been in service for several months; the other was about to be put into service, the railroad wanting to have a locomotive which was suitable for both types of service on its road. with the expectation of operating freight trains as well as passenger trains.

A number of the papers had made comparisons between the direct-current and the single-phase systems. He did not propose to enter into the problem in detail, but he wished to bring out some of the general comparisons between the two systems. As had been quite properly brought out in the papers, the real difference was that the single-phase equipment cost more, and the advantage of the single-phase system was in the lesser cost of the line for conveying the current from the power house to the car. The need of careful consideration of those features, and also of noting carefully the specific conditions on the road which was under consideration, would be brought out if some of the figures which had been given in the several papers were examined. The different conclusions which might be drawn from a slight change in the conditions or in the assumptions was thereby shown. In Mr. Hobart's paper two elements were considered. First, regarding the equipments, Mr. Hobart went into many details which had already been mentioned in the preceding discussion, and the accuracy of data employed had been vigorously criticised. On the other hand, the second element, the transmission, which was by some recognized as the large element to be considered, and certainly a very important one, received almost no consideration at all. Mr. Hobart passed all that over by a statement of the cost of electricity at the car, the figures being given as 0.90*d*. for the direct-current and 0.72*d*. for the single-phase, the former being 25 per cent more than the latter. The whole question of transmission systems and of power supply was included in that simple comparison, in which the direct current was said to involve 25 per cent greater cost than the single-phase per unit of power at the car, irrespective of the efficiency of the car motors. The losses in the direct-current system were greater than in the single-phase system between the power house and the car. The average all-day and all-year efficiency of a sub-station varied through wide ranges depending on the kind of service, the relative size of the sub-station, and the relation between the capacity and the average output, the load factor. For general average conditions he believed that an efficiency of some 80 per cent for the sub-station was probably higher than

would ordinarily be obtained, and was certainly much higher than is now practically secured on some roads which are in operation. Assuming however an efficiency of 80 per cent, it was found that for each kilowatt-hour delivered at the car, 1.25 kw-hr. must be generated in the power house. Hence, the sub-station loss will increase the power consumption over that required for the single-phase system by 25 per cent per kw-hr. at the car. That, however, was the ratio which Mr. Hobart had taken, allowing nothing for the greater first cost of the direct-current sub-station or for the attendance and operation of the sub-station. Those elements would evidently increase very considerably the cost of direct-current power. In Mr. Pomeroy's paper (Pars. 186 and 187) some figures were quoted from a paper by W. J. Wilgus concerning the New York Central Railroad, it being shown in Par. 187 that the total cost of power was 2.60 cents per kw-hr. Of that amount a trifle over 1 per cent, or only 40 per cent, was charged to the power station, and 60 per cent to the transmission and sub-stations. Sixty per cent of the cost of power at the car was required to get the power from the power house to the car. It showed in that system, where the transmission was within a radius of some ten miles, that the cost of transmission and distribution were very important items compared with the initial cost of power. If a fair reduction was made, taking the cost of the sub-station part for alternating-current as roughly about a quarter of that for direct-current sub-stations, one could obtain from the table in Par. 187 a ratio between the cost of direct-current power and the cost of alternating-current power which would show the cost of the direct-current power to be not 25 per cent greater, but 50 or 60 per cent greater than the cost of the single-phase power. If those figures were applied to Mr. Hobart's paper, there would be quite a material change in the results. The cost of power had been passed over rather lightly in the paper, although the cost of power was some 60 per cent of the total cost, 40 per cent being made up of various other elements, such as rolling stock and the like, on which he laid great stress. If the foregoing deductions were correct, there had been an error of some 25 per cent in the cost of the direct-current power, which would materially change the results and cut in half the gain which Mr. Hobart had found in favor of the direct-current system, without taking into consideration the errors which had been pointed out by others regarding the motor equipments. In other words, slight differences in assumptions might make a very considerable difference in results.

He had not been able to come to any satisfactory conclusion with regard to the comparison between the systems made in Mr. Carter's paper. Mr. Carter stated (Par. 47), that although both motors are dynamically capable of working the service, the former alone had sufficient thermal capacity for the purpose, the other having to dissipate three times as much energy as it can get rid of by natural cooling. That certainly could not be taken as a reasonable statement, because it would be evidently impossible to work them if they were generating in themselves three times the heat which could be dissipated. In American experience motors had been running for some years, but they had not yet attained the temperature which the passage he had quoted indicated. There might be some slip in the statement, or some other condition which he did not understand, because on its face the statement was absurd.

Some interesting figures were given in Mr. Potter's paper, but he would like to consider the illustration given in the Table 17 for interurban electric service from two points of view: first, as to the figures given and the assumptions made and, second, as to the completed system. He would not go in detail into certain minor points, about which he believed there was some ground for discussion. He noted, for example, that the maximum speed of the single-phase cars was to be 55 mi. an hour, and that of the direct-current cars 48 mi. an hour. He believed that requirement was excessive for the service, and would impose serious restrictions or extra cost on the alternating service. He noted also that the electrical maintenance for the alternating current was given as 1½ cents per car-mile. That differed greatly on different roads. In considering a new system, due consideration ought to be given to what could be done under established conditions. Taking, for instance, a single-phase road which had operated for a longer time than any other road, which now covered 100 miles and was doing a heavy service with large cars, the actual electrical maintenance over a period of three years had averaged less than 1 cent per car-mile as against 1½ cents given in the paper, or 50 per cent more. A correction had been made of a misprint in the cost of the single-phase cars, reducing that figure something over $50,000. He would not argue as to the cost per car, though he regarded it as too high, but another reduction should certainly be made in the total cost of the car equipments. The road was one which required six cars in service at one time. How many cars should a road purchase in order to maintain six cars in service? That was a question of judgment and of experience on which there

might be various opinions. He thought, however, all would agree on one thing, namely, that the figures given in the paper were excessive. Of the direct-current cars fifteen were provided in order that the six cars which were required for simultaneous working under the schedule might operate. For the single-phase cars the requirement was that for every one in service two should be idle as reserve, making a total of eighteen. From experience and also on general principles, he believed both the total number and the difference were too great. If, therefore, the number of cars was reduced to, say, ten cars of each kind, the excess cost of the single-phase cars would be brought down very much; and this reduction in the largest item in the final summary would make the total first cost of the single-phase system less than that of the direct-current. Without analyzing closely or giving comparative figures in detail, the point he wished to make was that by slight differences in assumptions and changing assumptions which were apparently not well founded, very radical differences could be made in the final results. Without discussing further the details of the comparison, or calling attention to other minor matters, he wished to point out the facts connected with the two roads as a whole. It appeared from Tables 19, 20 and 21 that the feeder requirements were for the 1200-volt direct-current road that the line should be sufficient for starting one car and running one car as the momentary maximum demand between stations. As the stations in that case were 28 miles apart, and as the conditions were substantially the same over a considerable distance near the center, there was therefore a distance of 10 to 14 miles over which the limit was the starting of one car and the running of one car. Literally, therefore, two cars could not start without exceeding the special maximum momentary demand between the sub-stations. The alternating current was about on the same basis; two cars might start, but the sub-stations were farther apart. What did that mean? It meant a line which could run on regular schedule with cars one hour apart. It seemed to preclude the operation of trailers, or at least the operation of two-car trains and certainly of three-car trains; it would presumably prevent the making up of time if one car got behind time. If one car got out of its regular place on the road, the system could not operate properly. If three cars were to get on to the middle of a section, it would overload it, and the greater the overload the lower the voltage, and the slower the cars would run. In such a case as the visit of The Institution of Mechanical Engineers, instead of starting up a train of two, three, or four cars, they would

have to wait for one-hour intervals before different sections of the party could travel. How could that be remedied? It could be remedied by increasing the other element, the line element. What would that cost? The capacity of the single-phase line would be doubled by doubling the number of sub-stations as against doubling the sub-stations on the direct-current line, but in one case the sub-stations cost only $20,000 and in the other case $106,000; one had an annual maintenance of $600 and the other of $3200. Consequently, if the line had to be increased in the alternating-current system, that could be done at a very little cost, but in the direct-current system at a very considerable cost. In the assumed typical interurban service, therefore, he wished to point out that an apparently excessive amount has been put in for the rolling stock, whereas the line requirements had been put in at a minimum, and were only able to operate 33 or 40 per cent of the cars provided and had no provision for handling other than the regular heavy service.

He wished, in conclusion, to say a few words as to the present condition of single-phase work. The line to which he referred as being the oldest single-phase line was operating in Indiana, a State which was permeated with electric railways, most of which were direct-current. In an official report which was made not long since, a comparison was given in which it was shown that the operating cost per car-mile of that single-phase road, which was operating at the highest schedule speed of any interurban road in the world, was less than that of any other road in the State operating interurban service of the same general character and radiating from the same city. The New York, New Haven & Hartford Railroad, which was, in America at least, the only distinctively railway trunk-line service which was operated electrically, employed the single-phase system. Everything else was put in for terminal, tunnel or special conditions; but in the case to which he referred, it was a purely trunk-line service. Therefore the only real trunk-line electrification was on the single-phase system, and, so far as he knew, the only steam railway company which was now proposing extension and was actively working forward to it was the New Haven company, which was purchasing new locomotives to determine a type adapted for passenger and freight service, and was designing its overhead structure for an extension of its single-phase system.

H. M. HOBART said he desired to make a few remarks on Mr. Potter's paper. The data in the paper were at many points sub-

stantially in agreement with his own results, but such divergencies as existed were in the direction of making out slightly too good a case for the continuous electricity system and too severely representing the weak points of the single-phase system. Nevertheless there remained a slight balance against the single-phase system for such a case as this road, and he was satisfied that by modifying Mr. Potter's figures by the substitution of data which he considered more correct, the result would be that it would be more economical to employ the single-phase system in this case than to employ the continuous electricity system, taking for both systems the costs and properties corresponding to their present development. Translating Mr. Potter's 2000-lb. tons into 2240-lb. tons and his costs from dollars into pounds sterling, Mr. Potter's single-phase car of Table 17 worked out at a cost of £89 per ton as against only £64 per ton for his 600-volt continuous electricity car. Now, for so very moderate a service as 33 miles per hour and one stop every 3 miles, the weight of the electrical equipment was, even employing single-phase apparatus, but a very small percentage of the weight of the car, and could not affect the total price of the car to nearly so great an extent as in severe service, where the weight of the electrical equipment was a large percentage of the weight of the car. Thus it was not reasonable to assign to the single-phase car a 39 per cent higher cost per ton, as had been done by Mr. Potter. From Table 9 of Mr. Hobart's own paper, he had taken out the costs per ton and had compared them with Mr. Potter's values. These were given in Table 31.

TABLE 31 COMPARISON OF HOBART AND POTTER VALUES

Estimator	Schedule Speed in mi. per hr.	Distance between Stops in Miles	Cost per Ton		Percentage by which B Exceeds A
			A Continuous Train, £	*B* Single-Phase Train, £	
Hobart	30	1.32	81	92	14
Hobart	22	0.88	73	82	13
Potter	33	3.0	64	89	39

According to Mr. Hobart's own data, Mr. Potter's single-phase car should have cost only some 12 per cent more per ton than his continuous electricity car. A study of the figures in the Table 31 revealed uniformity in the values for the three continuous electricity

cars (£81, £73, and £64 per ton) for the three services, and if Mr. Potter's value for the single-phase car were reduced to some £72 per ton, it would be much more reasonable. If, however, as may be inferred from condition *g* (Par. 126), namely, that the car is to operate on existing 600-volt city tracks, Mr. Potter's single-phase car was provided with equipment permitting it also to operate over 600-volt continuous electricity lines in towns through which the route passed, this would obviously bring up the weight and cost. But it was not equitable to the single-phase system, when working out a comparison of this sort, to make it bear this extra cost. Mr. Hobart was of opinion that after debiting the single-phase car with such a great first cost, Mr. Potter was decidedly wrong in giving it a life of only 12 years as against the life of 15 years assigned to the car equipped with continuous electricity apparatus. In view of these points Mr. Hobart considered that, leaving out the possibility of operating the single-phase car over city tracks equipped for 600-volt continuous electricity, Mr. Potter's figures should be modified so that in Table 17 of Mr. Potter's paper the cost of the single-phase car should stand at $14,000, instead of at $17,000, and that Table 21 should be modified to correspond to a life of 15 years in place of 12 years, for the single-phase rolling stock. With these high figures for cost, the single-phase car ought to be as reliable as the continuous electricity car, and only 15 single-phase cars should be required. Consequently the capital cost of the single-phase cars would aggregate 15 × $14,000 = $210,000, instead of the $306,000 in Table 21. A careful revision of the data would be found to reverse the results, and they would then substantiate Mr. Hobart's contention that the single-phase system was more appropriate for the road in question than was the 600-volt continuous electricity system, and that for such a case there was little to choose between the single-phase system and the 1200-volt continuous electricity system.

From Table 22 it could be shown that the costs which were taken into account by Mr. Potter came to a matter of some 8*d*. per car-mile, irrespective of system. For such a system a further 8*d*. per car-mile would have to be spent for costs other than those entering into Mr. Potter's calculations. Thus, the total costs if worked electrically would probably be of the order of 16*d*. per car-mile, and would certainly be greater than 14*d*. per car-mile, at any rate for such conditions as obtain in England. On urban and suburban railways in this country it was considered decidedly satisfactory when a road's gross takings amount to two-tenths of a penny per seat-mile. Mr.

Potter's cars provided 60 seats, and on the basis of 0.20*d.* per seat-mile, the gross takings work out at only 12*d.* per car-mile. Thus, under such conditions as applied in England, such an electric road could only be run at a considerable loss. Such a road was an excellent instance of a case where the use of electricity would be a mistake, and where steam was distinctly more appropriate. From the standpoint of the single-phase system, the irony of the situation consisted in this, that wherever a case arose where the single-phase system was more appropriate than the continuous electricity system, steam would usually be found to be superior to any electrical system.

Mr. Hobart found that Mr. Potter's energy consumption (Table 17) worked out at 90 watt-hour per (2240 lb.) ton-mile for the continuous electricity car and at 98 watt-hr. per (2240 lb.) ton-mile for the single-phase car. Only about half this energy consumption should suffice for the conditions of test runs over a good, straight, level track at a schedule speed of 33 mi. per hr., and with a stop every 3 miles. It would be of interest to hear from Mr. Potter whether in America the exigencies of everyday service involved a margin of practically 100 per cent or whether any considerable portion of the difference was to be ascribed to the condition of the track—lighter rail, or prevalence of grades and curves or snow and wind. If the values given for the consumption at the car included any considerable amounts employed for heating the car, as was customary on many roads of this character in America, it would be of interest if Mr. Potter would split up the input into that required for traction and that required for heating, as the former consumption alone would occur in the motor equipment. At so low a schedule speed as 33 mi. per hr., with such considerable distances between stops, it would appear that Mr. Potter's high value for the consumption per ton-mile could hardly be ascribed to excess air friction due to single-car operation. In Table 32 were given the items in the last column of Mr. Potter's Tables 21 and 22 side by side with Mr. Hobart's revision of his data.

In the last column of Table 32, Mr. Hobart took Mr. Potter's estimates and modified them in those respects in which some fundamental misconception interfered in his opinion with their appropriateness. It was to be noted that the first cost of the single-phase system was, according to Mr. Hobart's revision of Mr. Potter's estimate, 23 per cent less than the first cost of the 600-volt continuous electricity system and 11 per cent less than the first cost of the 1200-volt continuous electricity system. In most instances of railway electrification

as at present contemplated, a considerably lower first cost would, in practice, constitute a great advantage, even though the total annual cost were a trifle higher in consequence.

TABLE 32 SUMMARY OF COSTS, 6000-VOLT SINGLE-PHASE SYSTEM

		Potter	Hobart
First Cost	Transmission	$ 84,400	$ 84,000
	Sub-stations	20,000	20,000
	Secondary distribution	190,000	190,000
	Bonding	40,000	40,000
	Cars	360,000	210,000
	Total	$640,000	$544,000
Annual Fixed Charges	DEPRECIATION		
	Transmission	$ 2,500	$ 2,500
	Sub-stations	600	600
	Secondary distribution	8,800	8,800
	Bonding	3,200	3,200
	Cars	22,600	9,700
	Total depreciation	$37,700	$24,800
	INTEREST AND TAXES		
	Interest 5 per cent, taxes 1.5 per cent of cost of electrical material	45,000	35,300
	INSURANCE		
	1.5 per cent of sub-station and car costs	5,700	3,500
	Total fixed charges	$88,400	$63,600
Annual Operation and Maintenance	Transmission	$ 3,500	$ 3,500
	Sub-stations	500	500
	Secondary distribution, including bonds	10,000	10,000
	Cars	30,100	24,000
	Power at 1 cent per kw-hr	49,000	49,000
	Additional cost maintenance of track and roadway, shops and supervision due to heavier cars and more expert supervision required for the single-phase	10,900	4,000
	Total	$104,000	$91,000
Summary	1 First cost	$694,000	$544,000
	2 Fixed charges	88,400	63,600
	3 Operation and maintenance	104,000	91,000
	4 Annual cost (Item 2 + Item 3)	$192,400	$154,600

It was a pity that so great a difficulty was associated with distinguishing between cases. The single-phase system was, as he had undertaken to explain in his own paper, distinctly inferior to the continuous electricity system for a schedule speed of 22 mi. per hr., one stop every 0.88 mile and a service of one train every 10 or 15

minutes. On the other hand, for a schedule speed of 33 mi. per hr., one stop every 3 miles and only one train per hour, the single-phase was as good as or even superior to the continuous electricity system, and the steam locomotive was superior to either system. Where there was any considerable superiority as regards economy, of one electrical system over another, as applied to a particular section of railway, then it would usually be impracticable to make the sacrifice entailed in employing for that section an electrical system which, while much more appropriate for other sections of the railway, was inferior for the section in question. But how did the case actually stand as between the two leading electrical systems—the continuous electricity system and the single-phase system? For dense urban and suburban traffic, fairly general agreement was gradually becoming more apparent to the effect that electricity excelled steam, and furthermore to the effect that the continuous electricity system had decidedly greater earning capacity than had the single-phase system. For a much less dense traffic such as the case worked out by Mr. Potter, where electrification was, at the best, a doubtfully sound project, if it were nevertheless for any reason considered, one found that, although the single-phase system was according to his revision of Mr. Potter's calculations the most appropriate, it was so closely pressed by the continuous electricity system that there would be no serious sacrifice involved in employing the latter system in the event that it should be decided to employ electricity instead of steam. Thus one must conclude that the single-phase system was by no means suitable as a universal system of railway electrification, but that the continuous-electricity system had much greater claims to be thus designated, since it was distinctly more economical than the single-phase system when employed for dense urban and suburban sections of a railway, and was only very slightly less economical than the single-phase system for a road characterized by a very sparse traffic with infrequent stops and relatively low speed, such as one car per hour, one stop every 3 miles, and a speed of only 33 mi. per hr. If, therefore, the advantages of uniformity should in the long run be found sufficient to justify employing other than the most appropriate system on each section of a railway or for each class of traffic, then there was, in his opinion, which has been formed as the result of careful analyses of the present situation, every reason to look to the ultimate adoption of the continuous electricity system. But whenever it was required to consider a section of railway by itself, then for the conditions of such a 100-mile line as that studied by Mr.

Potter, no economy would, in his opinion, be sacrificed by the employment of the single-phase system instead of the continuous electricity system.

ANGUS SINCLAIR[1] wished to make a few remarks about that phase of the discussion which related to extending electrical operation to freight service. Mr. Westinghouse seemed to think that that would gradually be done, but so far as his (Dr. Sinclair's) experience had gone with railway work, he did not think there was the least indication that such a time was coming. When a man had sympathies in any direction, he was very liable to allow a great many things to sustain those sympathies which had very little bearing upon them. In connection with that, he always thought of the rapid effect of changes that had been made on some railways in America in freight service. The hauling of freight trains went on very steadily, with fairly economical loads, up to a certain period, when some railroad managers found that by using enormously heavy locomotives a slight reduction in the cost of haulage could be effected. They happened to be in a good position to make the change, and they carried it out without apparent loss, but without particular gain. There were others who were moved by the arguments they heard aboutthe reduction of the expense of haulage, who went into the business in the same way and brought their railroads practically into bankruptcy. They said they would get similar locomotives with very high hauling capacity, and orders were given for them, without due consideration being paid to the changes required when heavy locomotives were introduced. It was found immediately the engines were put in service that the track and the bridges were too light, and the railway companies therefore had to improve the track and change the bridges; in fact, they had to go to enormous expense with regard to the arrangement of the very heavy train service, with the result that instead of there being a reduction of expenses for doing the work, a great mass of debt was piled up which sent the railway companies into the hands of the receivers. It was necessary to consider such questions when an enormous change such as adopting electric motors instead of steam locomotives was under consideration; and he thought the lessons that railway managers in the United States had learned from the rapid change of power were liable to influence those who received the suggestion that electric motors should take the place of steam locomotives.

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Another point to be borne in mind in connection with freight haulage in the United States was that there were great differences in the various localities. There would frequently be a range of 1000 miles very sparsely inhabited, where there was little freight at one time and enormous quantities at others, the road then being pushed to its greatest capacity at times and nothing to haul at other times. The conditions for the country as a whole were not suitable. It was entirely a different question from that of operating suburban business with electrical traction, where there was a certain amount of close contact with the work to be done. He believed that concentration of traffic was necessary to make electric operation of railways a paying improvement. He thought from what he had seen of railway operating in the United States and on the American continent that the chance of electric traction for freight was very slight indeed.

J. G. WILSON[1] desired to consider one point in Mr. Westinghouse's interesting paper which he thought was the keynote of that gentleman's contribution. The author advocated the adoption of one system of electric traction to the exclusion of all others, and the standardization of its details. He wished to consider that proposition from a railway company's point of view owning steam roads which were susceptible of profitable conversion to electric traction, but which had not yet been converted. Three facts had been established so far from the actual results of electric traction: first, on suburban roads with heavy and moderately heavy traffic, conversion to electric traction was capable of effecting a considerable reduction in working costs, even taking into consideration the extra capital which had to be expended. Secondly, the adoption of electric traction on suburban roads gave really the only effective and satisfactory means of competing with other methods of suburban transit. Thirdly, there were interurban routes, and possibly also, with all respect to Mr. Sinclair, there might be areas of exceptionally heavy freight movement where the adoption of electric traction might offer advantages, which the improvements in the details of electric equipment continually tended to increase. The actual progress of conversion of steam roads to electric traction was not commensurate with those facts. It was no doubt natural that that should be so, and he took it that among the many reasons for it, one was the fact that there were at any rate two proved methods of making the conversion, sup-

[1] Newcastle-upon-Tyne, England.

ported by such eminent authorities as Mr. W ___inghouse and many others. The fact that there were two such methods could not but perplex the railway man himself. Mr. Westinghouse advocated, as a method of removing that bar to progress, the adoption of one system of electric traction and the exclusion of the consideration of others. He wished to be understood as being in entire agreement with Mr. Westinghouse so far, that if such a thing were practicable, it would have many desirable results; but he could not escape from the present conclusion that such a course would be impracticable, and if impracticable it was not absolutely necessary; and, further, it was not economically sound. In order to test its practicability, he wished to take an illustration from this country of two railways, for example, the Great Eastern and Great Northern. The Great Eastern had certainly the heaviest and most important suburban traffic in the United Kingdom. The Great Northern Railway, on the other hand, its near neighbor, had a relatively small suburban traffic but an important mineral center, where the consideration of electric traction might come up in the future. It could be shown that the cheapest method of dealing with the suburban problem on the Great Eastern Railway was the adoption of the direct-current system; but to anyone considering the problem of the Great Northern Railway's mineral traffic, it would be impossible not to take into consideration the claims of the single-phase system. If one of those railways, for the sake of interchange of traffic with the other, was going to give way to the other, which was it to be, and what inducement could be held out to the railway company which lost an immediate advantage in the matter? With regard to the question of whether such a selection of system was necessary, he did not think it could be too emphatically insisted upon, for the sake of the railway companies, that whereas one system could not be adopted for all cases, yet in any individual case the cheapest and the best system could be adopted with a great degree of certainty.

Lastly, he did not think that to delay the conversion to electric traction for the sake of arriving at uniformity was commercially sound, because the advantages to be gained were remote and problematical, and the advantages which in the meantime were being foregone were real, and too large to enable the railway company to afford to lose them.

F. R. HUTTON[1] said he desired to refer to the feature of the discussion which had been brought out by Mr. Sinclair and one or two other speakers. Dr. Goss was known to a great many, if not to all of those present, as one who had had the opportunity, in the location of his university, to make very elaborate and complete studies of the problem of the steam locomotive, and engineers owed to him an immense area of suggestion for its improvement. Mr. Sinclair had said in reference to Par. 212 of Mr. Westinghouse's paper that the latter very plainly desired to complete the electrification of all railways. That desire perhaps had overmastered Mr. Westinghouse's recognition of what another speaker had characterized as the broadness of the subject. Conditions of a very special sort presented themselves in the United States, or in any country of large extent as over the great stretches of prairies, where on some of the railway lines a single tangent was long enough to see the curvature of the earth on it. The conditions respecting the transmission of electric power over those great areas, where there were no terminal problems to be met, and no centers of distribution at short intervals, but where long, unbroken freight trains ran over thousands of miles, were so different from those where electrification had so far been completed that it was a little premature to say, with the great emphasis laid upon transmission loss, that those conditions were such that the electrification of railways was a pressing problem there, or that propulsion by transmitted energy was worth present consideration. There was no question that it was of great importance where there were a number of cities close together, strung like beads upon a string; but the conditions of those long, unbroken tangents were quite different from those in Great Britain or any other thickly peopled country and elsewhere where the distances were short. He thought also it was only fair that those who now favored the electrification of branch lines under the conditions which belonged to those long straight tangents should be very earnestly commended to examine the advantages belonging to the introduction of the motor-driven car, in the sense of an internal combustion motor, for branch line service. Here there were practically no losses in transmission, no matter how long the distances from the power station. This has seemed to many to be a solution for that class of traffic, passenger and freight, which for many years they have most earnestly commended. Furthermore, on many square miles of western parts of the United States, there was no head of

[1] Honorary Secretary, Am.Soc.M.E.

water available for power, and the cost of fuel for isolated power stations driven by steam would begin to offset some of the advantages of the electric system. The steam locomotive was not yet doomed by any means.

F. W. CARTER, in reply, said that Mr. Dalziel, referring to the question of the efficiency given in his (Mr. Carter's) Figs. 5 and 6, said that he had obtained an efficiency of 93½ per cent. He did not know where Mr. Dalziel obtained that figure, but if he was considering the efficiency of the motors exclusive of the gears and loss of friction, he thought the figure was probably about correct, and there was nothing remarkable in it. The average of the running range at full voltage was, he thought, probably 94 per cent. Mr. Dalziel suggested that he could have improved the showing of the single-phase motor if he had chosen different motors, so as to get the same free running speed in Fig. 5 for the two motors. He did not think the free running speed was a matter of any particular importance in short runs, because that speed was never reached. The reason that particular gear was chosen was in order to obtain the same margin in the schedule as with the two motors. If reference were made to Fig. 5 it would be seen that the running curves were continued by dotted curves, and came up to a certain braking curve, which included the same area, as the main curve, that is, the distance run was exactly the same, and for the two motors the distance was run in the same direction, about 110 or 111 seconds without any coasting. That feature settled the gear, and not the free running speed, which was of no particular importance. It was the margin in hand for making up lost time which had been chosen as the same in the two systems.

Mr. Scott had made some comments on the statement in Par. 47 that although both motors are dynamically capable of working the service, the former alone had sufficient thermal capacity for the purpose, the other having to dissipate three times as much energy as it can get rid of by natural cooling. It was not suggested in that discussion of a comparison of the motors that that particular single-phase motor would be used for that service. All he wished to point out was that the single-phase motor was apparently dynamically suitable for the service, but it was not one that could be used unless sufficient forced draft were obtained to carry off the extra heating. As a matter of fact, the continuous-current motor was running at about the limit of its thermal capacity with natural cooling. That was the explanation of Mr. Scott's difficulty; it was not

suggested that motors should be run, one having three times as much loss as the other.

H. H. BARNES, JR.,[1] in replying to the discussion on behalf of Mr. Potter, said he would limit his remarks to the criticism which had been made of the tables relating to interurban electric service (Tables 17–22). It had been stated that the number of cars chosen for the three classes of equipment was excessive. In the footnote to Table 17, figures taken from present practice on the other side were given, and it was with these in mind that the corresponding figures in the tables had been selected. For the sake of argument, however, he would admit that the assumptions were wrong. In order to illustrate the effect of a radical change, he had hurriedly checked over the figures on the basis of there being only half the number of cars shown. If this were actually the case, it would lead to conditions under which the road could not be operated. Nevertheless, on that basis he found that the difference in the annual cost, consisting in the fixed operation and maintenance charges, instead of being $32,000 would still be approximately $21,000 in favor of 1200 volts, as compared with an alternating-current system. While it was true that a reduction in the number of cars meant a more rapid decrease in cost for the alternating than for the direct-current equipments, the fact remained that even a reduction of one-half in the number of cars would enable the alternating-current system to catch up by $11,000 only. The remaining balance of $21,000 in favor of 1200 volts would still represent about 14 per cent of the estimated total annual cost of running the road.

Going to the question of the inadequacy of the feeder-copper and of the sub-station equipment, with the above-mentioned $21,000 one could buy, if capitalized, a large additional amount of feeder-copper, and materially increase the kilowatt capacity of the sub-stations as well. There were a number of items of sub-station and feeder cost which would not be affected by such a change; one had only to care for the purchase and maintenance of the items directly involved, such as rotary converters and copper conductors. It was, therefore, evident there was margin to make a favorable showing for 1200 volts, even with marked changes in the underlying assumptions.

In regard to one further point, the figures for maintenance used for the alternating-current equipments had been spoken of as high.

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He believed, however, they were not unreasonable. As contributing towards the increased cost of maintenance, such features as brush maintenance might be mentioned. Their experience on interurban work indicated for a given equipment a ratio of about 100 to 1 in favor of 1200 volts. Furthermore, he believed he was correct in saying that the actual number of men employed for comparable service on interurban roads in the United States was as great for alternating-current as for 1200 volts, notwithstanding the attendance required in the direct-current sub-stations. The men saved in the sub-stations were needed in the car barns of the alternating-current lines. While this was not a particularly important point, it confirmed the tendency towards increased cost of maintenance of alternating-current equipments.

In conclusion, he wished to point out that while the discussion had to a great extent dealt with the relative merits of the alternating and direct-current systems, Mr. Potter's paper appeared to him to be of special value in having emphasized the merits throughout a wide field of the 1200-volt system as compared not only with alternating-current systems but with the 600-volt direct-current system as well.

W. F. M. Goss[1] desired to remind the meeting, before the President of The Institution of Mechanical Engineers resumed the chair, that Mr. Aspinall had been one of the important factors in England in promoting the introduction of electrical transmission in this country, and he was sure all present would be glad if Mr. Aspinall would make a contribution to the discussion.

JOHN A. F. ASPINALL said that the passage of the members of The American Society of Mechanical Engineers through Liverpool was so rapid that they did not even get a glimpse of the Liverpool & Southport Railway. If those gentlemen had an opportunity before leaving this country of visiting that line, which was the earliest main line in England to be electrified, they would be given every possible facility for seeing its operation and the nature of the repairs that had to be carried out, in order that they might be able to compare electric railway work in this country with that of America.

The diagram given in Mr. Westinghouse's paper, which illustrated the new electric locomotive that was constructed for the haulage of

[1] Vice-President Am. Soc. M. E.

the heavier electric trains, was of great interest. It was very soon realized on the Lancashire & Yorkshire Railway that if heavy electric trains were to be hauled, and the cost of repairs of the motors was to be kept down, it was absolutely essential to revert, to a very great extent, to locomotive practice, so far as large bearing surfaces, large journals and things of that kind, which locomotive experience had shown to be necessary in any hauling machines, were concerned. That practice, which was now being established in the United States, overcame the difficulty which he had previously pointed out in that very room, of the center of gravity of the motor trucks in the multiple-unit trains being so low that the weight was not spring-borne, and hence the wear and tear of the rails became excessive.

Going back for a moment to the Liverpool & Southport line, he wished to say that the experience of four or five years' running of that line, with a very large number of ton-miles, had continued to show that the system in operation was perfectly satisfactory. No trouble was experienced with the cars, nor with the third rail, the generating station, or the sub-stations. The only thing which, looked at from a commercial point of view, required correction was the wear and tear of the motor machinery. One of the speakers in the discussion had touched upon the question of the great diversity of opinion between experts and electrical engineers. He did not venture to decide between two such great authorities; he could only say, as the general manager of one of the English railways, that no general manager could afford for one moment to close his mind to the advantages of the possible utilization of either one system or the other, whichever might prove to be commercially right. The utilization of the rolling stock to its greatest possible capacity was one of those items to which much greater attention must be paid than to almost anything else. He was pleased, therefore, to see in Mr. Pomeroy's paper (Fig. 17) the diagram marked *ABCD*, which illustrated in a very clear and distinct manner what a very small proportion of the time of a locomotive, whether steam or electric, was occupied in doing useful commercial work. The diagram showed that 22 per cent of the time was occupied with repairs in the shops and maintenance, and he supposed, reconstruction; only 28 per cent of the time was commercially used; and, as was stated in Par. 167 of the paper, the balance, 50 per cent, represented the time at terminal yards and side tracks and awaiting orders, when the locomotive was under steam, with crew, and ready to go. There was more money to be made in the elimination of that 50 per cent out of the little diagram than from any of the variations of system which had been described.

He agreed with the speaker who deplored the diversity of view of the expert electricians as to the system to be adopted. This controversy had undoubtedly retarded the advance of electrical railway work. Although he was merely repeating what he had said before in this hall, as the electrical engineers were practically unanimous that the direct-current was most suitable for suburban work, and the single-phase for long-distance work, he could not see why both should not be used by the same company. A railway company having a large terminus in a great city, with a considerable suburban traffic as well as a long-distance main-line traffic, could have one common generating station for both systems. The superintendence, the staff, the building, the boilers, would be common to both; the generating machinery alone need be different. There was no reason why the third-rail conductor for the continuous-current system and the overhead equipment for the single-phase should not run into the same terminal. The multiple-unit, motor-driven trains would be used for local traffic, the main-line trains hauled by electrical locomotives. As soon as long-distance electric traction became a commercial proposition, the practical means of doing the work were at hand. There would be no more difficulty in hooking on an electrical locomotive built to suit either kind of service, than there was today with a steam locomotive.

CARY T. HUTCHINSON[1] wrote that Mr. Carter's paper entitled Electrification of Suburban Railways was of peculiar interest to him, inasmuch as the author therein announced his discovery of the importance of a quantity called by him specific acceleration, to which he (Mr. Hutchinson) devoted much time and thought in 1902–1903. He supposed that he had then written enough so that any engineer working in the same field would at least have referred to his paper; but not so Mr. Carter, who, on the contrary, implied that he (Mr. Carter) had discovered the value of the quantity in his earlier work; Mr. Carter referred to his own paper in the Transactions of the American Institute of Electrical Engineers, Vol. 22, p. 133 (erroneously given by him as Vol. 20, p. 991) and to his second paper in the Journal of the Institution of Electrical Engineers, Vol. 36, p. 240, in these words (Par. 41): "The above is an application of a method which the author has more fully elaborated elsewhere." In the first paper referred to, published in June 1903, there was not the remotest reference, expressed or implied, to this quantity; no reader of it would ever imagine that such a quantity entered into the question. In the British paper,

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January 1906, there was a variable expressed as speed multiplied by the square root of stops per mile; this was not at all the quantity in question, as it was a velocity, not an acceleration, and moreover, whatever it was worth, was due to the engineer of the General Electric Company, and not to Mr. Carter.

Neither of Mr. Carter's references had the slightest bearing on the subject. Mr. Carter defined the quantity as follows (Par. 39): "It will be seen that the acceleration referred to above, which will be called the specific acceleration of the schedule, is the same for the two curves, being the square of the mean running speed divided by twice the distance." This was identical, save for the factor 2, with the quantity that he (Mr. Hutchinson) introduced under the name "through acceleration" in his paper, The Relation of Energy and Motor Capacity to Schedule Speed in the Moving of Trains by Electricity, published in the Transactions of the American Institute of Electrical Engineers, 1902, Vol. 19, p. 129. The quantity was defined and named on p. 132–133. He elaborated the matter in a second paper, The Conditions Governing the Rise of Temperature in Electric Railway Motors in Service, in the Transactions of the American Institute of Electrical Engineers, Vol. 22, p. 657, 1903, the same volume that Mr. Carter's American paper was published in.

Mr. Carter had not grasped in full the relation of this through acceleration to the other factors in the problem, and he made several misstatements. But it was at present the writer's purpose merely to call attention to this curious rebirth of his through acceleration, and to the recognition, though tardy, of its importance. It was roundly condemned at its first birth.

PHILIP DAWSON[1] wrote that Mr. Hobart assumed that the cost of the distributing system was the same in the single-phase and continuous current. This was quite inadmissible, and both Mr. Potter and Mr. Westinghouse, in their contributions to this subject, clearly stated that the single-phase had the great advantage in having the cheaper distributing system. Mr. Hobart assumed that the output for the alternating-current motor equipment was only 6 h.p. per ton in the cost of the Brighton equipments, for which he (Mr. Dawson) was responsible. This was incorrect, first, because the weight of the electrical equipment was 36 tons and not 44 tons. Secondly, 6 motors were quite sufficient to run the schedule time with ease, and as a matter of fact had often done so. In any case it appeared to him that Mr. Hobart's method of reasoning was incorrect and really proved nothing.

[1] M. I. Mech. E., St. Stephen's House, Victoria Embankment, Westminister, S. W., England.

Mr. Hobart also assumed the cost per ton of equipment; all those who had to purchase electrical apparatus knew how erroneous such assumptions were. Mr. Hobart further stated that the cost of electricity delivered to the railway was 0.7*d.* per B.t.u.; this was a great deal too high, and, as a matter of fact, the line with which he (Mr. Dawson) was connected would very soon reach a point at which electricity would cost only ½*d.* per unit on their railway at the periodicity and the pressure at which they used it. Mr. Hobart, in his figures of cost of electrical energy per train-mile assumed that the electricity would cost them from 10*d.* to 15*d.* per train-mile; on the basis of the energy consumption which now existed and at ½*d.* per unit, this figure for their service amounted to only 4.83*d.* per train-mile. In this connection it must also be borne in mind that the South London line was a very bad line for running. It was full of short-radii curves, and there was a rising gradient in each direction out of each station with the exception of the termini. Out of Victoria Station there was a gradient of 1 in 64 for a very considerable distance, and owing to the congested nature of the traffic practically every train was stopped once or twice by signal on entering both London Bridge and Victoria. Although he had had no time to check Mr. Hobart's calculations, he believed there would be no difficulty in carrying out, under the Southport conditions of distance between stations, gradients, and curvature, the services there running at the present moment with the Brighton equipments.

He was entirely unable to understand Mr. Hobart's assumptions for charges for rolling stock, or his statement that the cost for electricity, plus individual charges, was 3*d.* higher for single-phase than for continuous current. He did not wish it to be thought that he was in any way criticising the continuous current, which gave such excellent results, and he thought it was a pity that at this stage an attempt to decrease the great advantages possessed by single-phase should be attempted by engineers. In electrifying any portion of a main-line railway system it must always be borne in mind that very large extensions might come about in the future, and even Mr. Hobart mentioned a 30-mi. radius. Under these circumstances it certainly appeared to the writer that the single-phase system could not be dismissed in the very simple way in which Mr. Hobart had attempted to do it.

Mr. Hobart suggested that the energy consumption on a test run on the train amounted to 79 watt-hr. per ton-mi. While these figures were those guaranteed by the manufacturers, actual tests

gave 66 watt-hr. per ton-mi. That there was a very large amount of spare power on the trains on the South London line, was shown by the fact that under ordinary running conditions it was quite possible to make up 2 minutes on the schedule run of 24 minutes. There were other figures in Mr. Hobart's paper to which he would like to have taken exception, and errors which he would have liked to correct if time had permitted; but in any case he thought he had shown that Mr. Hobart's conclusions were entirely vitiated by the results obtained on the South London line.

He though Mr. Carter's paper of great interest, but he would like to point out that the comparison of the cost as instituted by him between the South London and Tynemouth electrifications was entirely misleading, and that had he (Mr. Dawson) been installing the third-rail system on the South London line, the cost of doing this would have been greater than the single-phase system. In any case, in advising the adoption, which he did in the case of the Brighton Railway, he had to bear in mind possible extensions as far as Brighton; and experience had certainly shown that the adoption of his advice had proved most satisfactory to the Brighton Railway Company.

As regards the very able papers of Mr. Potter and Mr. Westinghouse, they were so full of figures that he had not time to criticise them very thoroughly. He would, however, like to point out that there was a very great discrepancy between the results obtained by these two eminent authors, who had had such vast experience in America, and who also had had the information and data of two such eminent manufacturing concerns as the Westinghouse and the General Electric companies, respectively. While Mr. Westinghouse distinctly proved that the single-phase system was by far the most economical, Mr. Potter succeeded in proving the reverse.

He thought this showed how easy it was to come to a false conclusion, unless every individual case was thoroughly investigated on its own merits by railway engineers. He would like to point out in this connection that the railway engineers of the various German states, Sweden, and Switzerland, and many other railway engineers, after the most careful consideration, came to the conclusion that for the electrification of any portion of a main-line railway—suburban, interurban, or long distance—the only really satisfactory system to be employed was the single-phase.

He did not give this as his own opinion, but only wished to refer to it as a general impression gaining ground in Europe.

J. R. WILLIAMS[1] wrote that Mr. Hobart showed that the one weak feature of the single-phase system, as applied to railway work, lay in the motor; this had a smaller torque than the direct-current motor, and its electrical efficiency was lower; therefore the current consumption per ton-mile was greater for the single-phase than for the direct-current motor. The power factor of a single-phase system was low, probably from 75 to 80 per cent, when connected only to induction motors, and in the writer's opinion the comparison of costs per kilowatt delivered to the train (Par. 88), namely, 0.72 per kw. for single-phase and 0.9 for the continuous-current, was too favorable to the single-phase plant.

The lower power factor reacted on the capital cost of the power station, by the fact that it required a larger station being built and equipped to supply a given system than would be necessary with the same system supplied by continuous current. Therefore capital cost and interest would be greater, and profits proportionately less, while the design and heavier weight of the train reacted upon the cost of upkeep of the permanent way.

If the problem were main-line electrification, then the single-phase was probably the more suitable system, as feeder losses would tend to equalize the costs of the two systems; but he would be glad if Mr. Hobart would extend his paper slightly by giving a comparison of the costs worked out for a continuous-current supply at 1200 volts as against the single-phase system. This would admittedly show a higher percentage in favor of the continuous-current supply, and in his opinion was the system which in the future will commend itself both to the Board of Trade and to railway managers generally.

WILLIAM CASSON[2] wrote: All engineers who are concerned solely with the operation of electric railways and not with the manufacture of any type of plant must echo Mr. Westinghouse's wish for unbiased discussion of all the various systems in use in all their bearings.

It is for this reason that he thought the tabular comparison drawn by Mr. Westinghouse between the direct-current system with three-phase transmission and the single-phase system must be treated with great care if it is intended to apply it to general cases as distinct from the case of the particular line to which it was intended to apply.

[1] Sheffield, England.

[2] A. M. I. Mech. E., Central London Rwy., Caxton Rd., Shepherd's Bush, W., London, England.

There being no scales attached to the tables and no absolute values given, the tables are a little difficult to criticise, but from the point of view of general application the following points seem to call for comment.

In Fig. 37, the loss in the direct-current contact line appears to amount to 14 per cent, which seems very high, since if this is the average figure the voltage variation between extreme points when trains are starting will be about 30 per cent.

Assuming, however, that this figure is right, the power delivered to the sub-stations appears to be 25 per cent more for the three-phase direct-current system than for the single-phase. Assuming for the sake of argument the same power factor for the two systems, the volt amperes in the transmission line of the three-phase direct system will not be more than 25 per cent higher than for the single-phase.

In Fig. 37, however, the actual (not percentage) transmission loss for the three-phase direct system is apparently 50 per cent higher than for the single-phase system, although the transmission line is also shown in Fig. 38 as costing 50 per cent more. As a matter of fact, with the same voltage between cores, a three-phase cable to carry the extra 25 per cent of load should not cost more than about 25 per cent more than a single-phase concentric cable, for the same total loss in the cable.

The assumption of equal power factors is however quite unfair to the three-phase direct system. With rotary converters the power factor of the transmission line can be kept at 0.98 under ordinary operating conditions. It never falls below this on the Central London Railway. On the other hand with the single-phase system there are motors with a power factor of 0.9 supplied from a contact line which with the track return forms a large inductive loop and which is in turn supplied through static transformers so that the power factor will almost certainly not exceed 0.8. It will be obvious therefore that the current in the transmission line, still assuming the high-contact line loss with which Mr. Westinghouse debits the direct-current system, will be the same in both cases, and therefore for the same total transmission loss the cost of the three-phase cable should not exceed that of the single-phase one by more than two or three per cent at the outside.

With a reasonable contact-line loss the advantage will probably be on the three-phase side with regard to transmission line loss and first cost.

The allowance of 20 locomotives appears to be very small for 100

miles of line. This is only about one-fifth of the average steam railway figure for this country. Of course the annual mileage for an electric locomotive will be much higher than for steam, but the traffic density must also be higher to justify electric traction at all. Even assuming that each locomotive makes 200 mi. per day or about 73,000 per annum, there will be only 20 trains in each direction per day on the line under consideration. On most of the electrified railways in this country the annual mileage appears to be about 50,000, but with higher speeds and longer runs between stops probably 70,000 might be reached, but it would be difficult to justify electrification of an existing or projected line with such low traffic density as one train per hour. On most electrified lines in this country the number of train sets exceeds one per mile of route, and on the underground and tube railways, which must be considered in any universal system, it is very much more, reaching 5 per mile on the Central London Railway, which is, however, an extreme case.

This point is an important one, as the cost of a single-phase locomotive appears to be 50 per cent higher than that of a direct-current one according to Fig. 38.

In Fig. 38 the cost of the single-phase contact line is shown as being less than one-half the cost of that for direct-current. There are no figures published as to the cost of the two single-phase contact lines erected on railways in this country, but there is no doubt it is very much higher than £1000 per mi. of track which is the cost of a single third rail erected and bonded complete.

In the system considered by Mr. Westinghouse, the third rail is supplemented by a copper distributing cable, which would form an additional item in the direct-current contact-line cost and might perhaps double it, but with a frequency of only one train an hour in each direction and an average contact-line loss of 14 per cent, the copper distributor would hardly be required, even on a 600-volt system with sub-stations 8 miles apart and certainly not on a 1200-volt system.

Taking into account then the small number of locomotives provided and the unnecessarily high cost of contact line and transmission lines assumed for the three-phase direct system it certainly seems that Figs. 37 and 38 are somewhat unfair to the last-named system, if they are considered as of anything like general application.

CLOSURES[1]

F. W. CARTER wrote that Mr. Dalziel had now explained his suggested 93½ per cent efficiency as having been obtained "by totalling the respective curves of output and losses on Fig. 5, and as the figure of 93½ per cent so obtained was not the free running but the efficiency overall from start to stop, it was a very high figure." The only overall efficiency which even approached Mr. Dalziel's figure was the purely fictitious one obtained by taking account only of the losses which went to heat the motors—core loss, copper loss, etc.—and comparing the figures obtained with the total input. If this was the efficiency Mr. Dalziel referred to, he might have obtained it with greater accuracy and less labor by simple subtraction; the motor loss was given as 6.75 per cent of the input, so that this efficiency was 100 − 6.75 = 93.25 per cent. This, however, was no real efficiency at all. The input curve, as could easily be deduced from Fig. 5, included some 13 per cent rheostat loss, so that the motor input was only 87 per cent of the equipment input. Thus the motor losses were $\frac{6.75}{0.87}$ = 7.75 per cent of the motor input, and what might be described, if it were any use, as the overall efficiency at the armature shaft was 92.25 per cent. But in addition to this, there was some 4 per cent gear loss, so that the overall efficiency of the motor was only about 88 per cent. Allowing for the rheostat loss, the overall efficiency of the equipment would be seen to be approximately 76½ per cent. Under the conditions he did not believe there was anything at all remarkable in any of these figures, and could only conclude that Mr. Dalziel had not succeeded in making correct use of the data available. It was barely possible that this might explain some of Mr. Dalziel's other difficulties.

In reply to Mr. Cary T. Hutchinson, he would say that he had not read Mr. Hutchinson's papers and was unaware that they dealt with the matter in question. He had unwittingly rediscovered and made some use of an idea which he was quite willing to believe originated with Mr. Hutchinson. He had himself, however, made no claim to being the originator of the idea, which he had not considered of sufficient importance to warrant the labor of historical research, and which moreover he regarded as implicitly contained in the work

[1] L. R. POMEROY did not desire to present a closure—EDITOR.

of Mr. Anderson,[1] mentioned in one of his references. Mr. Hutchinson had misunderstood his statement, "the above is an application of a method which the author has more fully elaborated elsewhere." He did not here suggest that he had elaborated the subject of specific acceleration elsewhere; had he done so he would not have discussed it in detail in the paper. He would assert, however, that the method of reducing diverse schedules to a common basis according to definite rules had been discussed in both papers referred to, and this was the meaning he had intended to convey in the above statement. The first paper dealt exclusively with this matter and the second partially. In the British paper, the credit for the underlying idea of the method as there used had been given to Mr. E. H. Anderson of the General Electric Company. Mr. Hutchinson had seen fit to make use of this admission to belittle the author's poor efforts. The use of speed multiplied by the square root of stops per mile as independent variable, whatever it was worth, was not Mr. Anderson's but the author's own way of using the idea, and differed totally from Mr. Anderson's. But if Mr. Hutchinson was unable to deduce a correct conclusion from inadequate information, he was no more fortunate in stating the nature of a simple quantity. Speeds multiplied by the square root of stops per mile was not a velocity but the square root of an acceleration, as he might apprehend if he considered that stops per mile was only another way of writing the reciprocal of the distance between stops. The square of this quantity was in fact much the same thing as Mr. Hutchinson's through acceleration and was commensurate with it in value. The idea of specific acceleration had been introduced into the paper for no other purpose than to drag in Table 2, and he had desired to bring this in because he was tired of the foolish comparisons that were continually being made on this side between services that were in no wise comparable. The engineer of the A & B Railway had but to give out that he had found an energy consumption of 100 watt-hours per ton-mile on his line, when the manager of the Y & Z Railway would show how he had found an energy consumption of only 80 watt-hours per ton-mile on his line, and how that accordingly his company had adopted the better system and so on. It was his feeble effort to relieve this country of some of this rubbish, by showing that the energy consumption on the A & B Railway might legitimately be

[1] It may interest Mr. Hutchinson, as one concerned about precedence, to learn that a set of curves embodying Mr. Anderson's conclusions and given by him to the author, are dated July 1901.

higher than on the Y & Z Railway, that had brought the author into collision with Mr. Hutchinson.

With regard to Mr. Dawson's remarks, the author would say that he had intended his investigation of capital burden in the case of the Tynemouth and South London electrifications to be regarded less as a comparison than as an example of possible divergence. He had not suggested, nor had he had any desire to suggest, that the whole difference lay in the system of operation selected; at the same time, since Mr. Dawson had raised the point, it could not be denied that the question of system had its effect on capital costs, and considering that the latter scheme showed a capital burden some three times that of the former, Mr. Dawson could hardly be serious in his claim that it would have been still higher had the same system as is used on the former railway been adopted.

It was a matter of some surprise that those who adopted the rôle of advocate of a system of operation seemed usually very desirous of establishing illegitimate claims for their system, often to the neglect of its real advantages. As for instance, when Mr. Dalziel (Figs. 42 and 43) went to much trouble to show that in a run without coasting and with a fixed rate of braking, he could alter the gear ratio without altering the running time, an obvious fallacy, when he might with justice have pointed out that the single-phase system as compared with the continuous-current system did not require to have so great a margin for making up lost time in the speed curve at constant voltage, as such an emergency could be met by running on an overvoltage tap. Thus he might legitimately have claimed the right to alter the single-phase gear ratio, if by so doing he could have shown decreased motor losses. Mr. Dawson doubtless had good reasons for recommending the adoption of the single-phase system for the Brighton Railway, and in fact the necessity of bearing in mind possible extensions as far as Brighton could not have been disregarded; but if in spite of the enormous capital burden of the South London electrification, he still had any impression that the single-phase was cheaper than the continuous current system for suburban work, it was not inappropriate for the author to suggest that Mr. Dawson should get further information as to the cost of the latter system.

H. M. Hobart wrote, in reply to the discussion, that for the purposes of the estimates in his paper he had taken the cost of electricity as delivered to the sub-stations, at the representative figure of 0.65*d*. In consequence of the capital cost and operating costs of

the sub-stations, he had taken the cost of electricity as delivered from the sub-stations as 0.70*d.*[1] for single-phase electricity and as 0.87*d.* for continuous electricity. It was the relative values of these two figures to which significance should be attached. The actual values depended upon the distance from the supply station and on the cost of fuel, water and labor, and on other considerations varying in every case. He had considered that the relative values of 0.70*d.* and 0.87*d.* respectively, for single-phase and continuous electricity as delivered to the railway in the form in which it was required for the propulsion of the trains, were fair representative values, the price for continuous electricity exceeding the price for single-phase electricity by 24 per cent. However, Mr. Scott expressed the opinion that the cost for continuous electricity should have been taken greater than that for single-phase electricity by 50 to 60 per cent, instead of by only 24 per cent. The method by which the author arrived at the latter figure could best be shown by taking the concrete case of the S.L.E. Railway with its 8.6 miles of route. The rolling stock comprised eight 3-coach trains, and in Table 13 he credited each train with an aggregate of 48,000[2]

[1] It was not correct to ignore all sub-station costs in the single-phase system. A certain capital outlay was invariably incurred for sub-station switch-gear and other apparatus, even when neither the pressure nor the periodicity required to be transformed. Of course the ratio would vary widely according to the conditions of each case. Mr. Scott took the cost of the sub-station part for alternating current as roughly about a quarter of that for direct-current sub-stations. Mr. Potter (Table 16) took the capital cost of the sub-stations for trunk-line service at over one-third as much for the single-phase as for continuous electricity, and for yearly operation and maintenance of sub-stations Mr. Potter took half as much for the single-phase system as for the continuous-electricity system. While Mr. Potter's percentages would, in his (Mr. Hobart's) opinion, usually be unfair to the single-phase system, it was equally or more erroneous to ignore sub-station costs in the single-phase system. In increasing the cost of electricity as delivered from the sub-station to 0.70*d.* as compared with a cost of 0.65*d.* for the electricity as delivered to the sub-station, he had very decidedly favored the South London Elevated Railway single-phase system whose 8.6 miles of route had no less than twelve elaborate boosting and sectionalizing switch-cabins.

[2] On p. 17 of The Light Railway and Tramway Journal for January 14, 1910, Mr. Dawson gave data from which it appeared that the South London Elevated Railway worked its present eight trains on the basis of some 46,000 miles per train per annum, which gave an average (for the 365 days) of 126 miles per train per day. But the normal service probably only required five out of the eight trains to be on the line on any one day and those five trains, on the days they were on the line, averaged $\frac{5}{8} \times 126 = 200$ miles per train per day. This

miles per annum. If the same service were performed by trains equipped with continuous-electricity motors, it would be seen from Table 13 that the consumption per train was 512,000 kw-hr. or $8 \times 0.512 = 4.10$ million kw-hr. per annum for the eight trains. The output from the sub-stations would be some 4.25 million kw-hr. per annum. For this particular service, some four or five trains per hour, two sub-stations would be appropriate for the 8.6 miles of line, and the load factor on the sub-stations might be taken at about 20 per cent. The peak load on each sub-station would be some $\left(\frac{4{,}250{,}000}{2 \times 8750 \times 0.20}\right) = 1210$ kw. A rated capacity of 1500 kw. of machinery in each sub-station, with a guaranteed capacity of, say 2500 kw. for intermittent overloads, would obviously be ample even for a service considerably more severe than at present provided by the S.L.E. Railway. The two sub-stations, complete, would cost about £15,000. We may take the annual capital charges on this outlay, corresponding to the 15 per cent on the rolling stock at 10 per cent, making an outlay under this heading of $\left(\frac{15{,}000 \times 0.10 \times 240}{4{,}250{,}000}\right) = 0.085d.$ per kw-hr. of output from the sub-stations. A further charge of 0.055*d.* per kw-hr. of output would amply cover wages, oil and stores.

For the train service at present provided on the South London Elevated Railway, the annual efficiency of these two sub-stations would be fully 89 per cent,[1] instead of the 80 per cent suggested

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service gave 64 trains per day in each direction, but in the article to which reference was made above, Mr. Dawson stated that this would be increased to 100 trains per day in each direction. The practicability of doing this, without adding to the present rolling stock, had yet to be demonstrated. It was however desirable to mention that the service had very recently (October 1, 1910) been increased to 75 trains in each direction on week-days and 30 on Sundays. This, when sub-divided amongst the eight trains, amounted to 54,000 miles per annum for each train. The final increase to the 100 trains per day which Mr. Dawson had stated in his article to be intended, would, if accomplished, bring up the average for each of the eight trains to 72,000 miles per annum.

[1] Mr. Aspinall showed (Proc. I. Mech. E., 1909, pt. 2, p. 454) that for 57,190 kw-hr. delivered from the sub-stations of the Southport Railway, on a certain day, there was a loss of 3480 kw-hr. in the rotary converters, and a loss of 1885 kw-hr. in the transformers. Consequently for the service on that road on the day in question (July 1906), the overall efficiency of the sub-stations was

$$\frac{57{,}190}{57{,}190 + 3480 + 1885} = 91 \text{ per cent}$$

He (Mr. Hobart) in taking 89 per cent for the sub-station efficiency was reasonably conservative.

by Mr. Scott, and which would appear to have been based on his impressions from interurban roads with a train every hour or so. With 89 per cent efficiency, the cost per kw-hr. of output corresponding to a cost of 0.65*d.* per kw-hr. of input would be $\left(\frac{0.65}{0.89} + 0.085 + 0.055 = \right) 0.87$. This confirmed the figure of 0.87*d.* which he took as the basis of his estimates, and was only 24 per cent higher than the 0.70*d.* which he took for single-phase electricity (as delivered to the railway's contact line), as against the 50 to 60 per cent higher price put forward by Mr. Scott. This disposed of the matter of the relative prices, and confirmed his figure of 1.24 for the ratio.

Coming to Mr. Dawson's criticism, he found this to be apparently rather than actually formidable. He proposed to show firstly, that he had real and well-founded reasons for adopting the figures to which Mr. Dawson took exception; secondly, that the acceptance of Mr. Dawson's corrections, far from improving the showing of the single-phase system, actually made it worse than his assumed figures; thirdly, that Mr. Dawson had as yet no cause for jubilation in the economic results of the South London electrification. Mr. Dawson stated that 0.7*d.* for single-phase electricity was a great deal too high and that the South London Elevated Railway would very soon reach a point which would cost only 0.5*d.* per unit as delivered on their railway at the periodicity and the pressure at which they used it. It would not have been desirable for him (Mr. Hobart) to employ so low a price in his comparison, for railway officials ought not to be too optimistically advised as regards the price of electricity, in comparing steam-locomotive working with electrical operation.

Thus from Par. 187 of Mr. Pomeroy's paper it was seen that the cost of the electricity as delivered to the sub-stations, was 0.66*d.* per kw-hr. (which was about the same as Mr. Hobart's assumption of 0.65*d.* per kw-hr.) for the New York Central Railway. On June 3, 1908, in giving evidence before the Parliamentary Committee on the London and District Electric Supply Bill, Mr. Forbes, general manager of the London, Brighton & South Coast Railway, stated that their contract with the London Electric Supply Corporation for electricity for the South London Elevated Railway was on the basis of a tariff ranging from rather more than 1*d.* down to ½*d.* per unit. Even now Mr. Dawson did not assert that they were obtaining electricity for 0.5*d.* per kw-hr. but simply said that it would very soon reach a point which would only cost ½*d.* per unit on their rail-

way at the periodicity and pressure at which they use it. If there were any definite basis for this assertion of Mr. Dawson's, it was that 0.5*d*. per unit was the limit of a schedule at which all power in excess of a certain quantity was charged. But they were concerned with the average price of all power, and not only with that portion which was in excess of a certain quantity. Mr. Hobart's 0.7*d*. per unit might thus be entirely consistent with Mr. Dawson's 0.5*d*. per unit. Even when the price of 0.5*d*. was reached, Mr. Dawson probably meant that it would apply to the electricity as delivered to their sub-station, or "distributing cabin" as Mr. Dawson preferred to call it. Consequently the costs associated with the price and operation of the distributing cabin ought still to be added.

Mr. Dawson and the London, Brighton & South Coast Railway were to be congratulated if they could obtain electricity for a railway load from a London supply company at a lower price than that at which it could be purchased on the Tyne. But so far as regards the comparison between the single-phase and the continuous electricity systems, the conclusions were but slightly dependent upon the basis prices assumed, so long as these were in the correct ratio to one another for the two systems; in fact. he (Mr. Hobart) was slightly favoring the single-phase system in taking fairly conservative values for the basis prices. But, to meet Mr. Dawson's criticism, he would take 0.50*d*. per kw-hr. for single-phase electricity, and $0.50 \times 1.24 = 0.62$ per kw-hr. for continuous electricity, the prices in both cases being on the assumption that the Electricity Supply Company, from whom the railway purchased the electricity, owned the sub-stations and provided the electricity at the above prices at the cables leading from the sub-stations to the contact rails or conductors or to the feeders from which these contact rails or conductors were supplied. Owing to the losses between the sub-stations and the trains, he would take the cost of electricity at the trains as 0.51*d*. and 0.64*d*. allowing 2 per cent loss in the single-phase system and 3 per cent loss in the continuous-electricity system. Thus, at the train he was taking the cost of continuous electricity per kw-hr., as 25 per cent higher $\left(\text{since } \frac{0.64}{0.51} = 1.25\right)$ than the cost of single-phase electricity.

Mr. Dawson put forward 66 watt-hours per ton-mile as the consumption at the train under the conditions of test runs. Although he found it impossible to deduce any final results from Mr. Dawson's various descriptions of his tests, the best he could do was to quote

from his (Mr. Dawson's) contribution to the discussion of some papers read at the Institution of Civil Engineers last winter. Mr. Dawson stated:[1]

In that connection he would like to give some results which he had obtained on runs made during the last few months on the Brighton line. They were test runs made under the best possible conditions, and the results he was about to give were results for test runs only. The various factors entering into the runs—amperes, volts, watts and speed—were all measured by instruments specially made for him. The speed record was in addition checked by another instrument kindly lent to him by Mr. Morgan, the chief engineer of the Brighton Railway Company. In such a way he thought he had obtained results which were as nearly accurate as any such measurements on a train by instruments could be. The tests consisted of a series of six runs between Battersea Park and Peckham Rye and back. There were four intermediate stops of 20 seconds at each station, and the average distance between the stations was ¾ mile. The shortest distance between any two stations was 1900 feet. The line was a hilly one with several gradients, some of as much as 1 in 91; and as the line was practically all curves, the conditions for such tests were not ideal. On those six runs the average energy used per ton-mile, measured on the train—not allowing, of course, anything for shunting, but allowing everything else—was 71.8 watt-hr. per ton-mile. The average speed, including stops of 20 seconds at the four intermediate stations, was 21.2 miles per hr. The maximum acceleration was 2.06 ft. per sec. per sec., and the average acceleration from rest to a speed of 37 miles per hr. was 1.5 ft. per sec. per sec., the train weight being made up to the figure agreed upon in the original contract, namely, 148 tons. The average power-factor for the six runs was 80.8 per cent. The starting current never exceeded on the level 6600 volts, 120 amperes, and the maximum current at any time never exceeded 184 amperes. It might also be interesting to give a few results for other distances. The distance between Denmark Hill and Peckham Rye was 4480 feet, and on test runs the consumption per ton-mile worked out at 68 watt-hours, while the average speed was 24.4 miles per hr. Between Battersea Park and Wandsworth Road, a distance of 3465 feet, the corresponding results were 22 mi. per hr. and 67 watt-hours per ton-mile. On Sunday, November 7, there were six trains running from about 9 a.m. till 6 p.m., at what it was proposed should eventually be the regular scheduled service, between Victoria and London Bridge, a distance of 8¾ miles, including 20-second stops at intermediate stations, in 24 minutes. A good deal of shunting had to be done on that day at various stations, in order to get out of the way of steam trains working the ordinary traffic. Over the whole day the average energy-consumption worked out at 81 watt-hours per ton-mile, and the average distance per train run on that day was just a little more than 100 miles. The average speed was about 25 miles per hr. excluding stops, and 21.8 miles per hr. including stops. The average distance between stations on that run was 4620 feet.

[1]Proc. Inst.C.E., vol. 179, pp. 128-129.

On p. 19 of "The Light Railway and Tramway Journal" for January 14, 1910, Mr. Dawson said:

> It may be interesting to note that during trial running over the whole line between Victoria and London Bridge, when six trains were in service and before the line was opened for public service, 80 and 81 watt-hr. per ton-mile was actually consumed at the point of distribution where the current is metered and paid for, this figure including train lighting and all energy used for shunting, for which no mileage allowance was naturally made. For the first week of regular service, the energy per ton-mile at the distributing point, including all energy used for shunting, non-productive mileage, lighting, repair shops, losses due to weather, and not allowing anything for weight of passengers, was 83 watt-hr. per ton-mile. Under these circumstances, the hope seems justified that the amount to be actually paid for, including all distribution losses, and including all the power and light used at the repair shops and for shunting and not allowing anything for weight of passengers or luggage carried, will be on the average and for a varying composition of train, well under 85 watt-hr. per ton-mile at the point where current is paid for. It must not be lost sight of that this figure is at the point of purchase and includes all line and distribution losses and possible losses due to bad weather, etc., and energy and light used in repair shops.

In view of the indefiniteness running through all these statements, he considered that he was fully justified in falling back upon the contractor's original guarantee of 79 watt-hr. per ton-mile as the basis for his estimates, and in view of the known efficiencies and properties of the equipments employed, his basic figure of 79 watt-hr. per ton-mile, was, in his opinion, the most appropriate and probable. By accelerating at a very high rate during test runs, a considerably lower figure could always be obtained on any type of equipment, but it could not be maintained during the conditions of routine service.

Taking the 66 watt-hours per ton-mile as a figure corresponding to test runs, it followed that Mr. Dawson's 4.83*d.* per train-mile was merely a paper estimate and not what the South London Elevated Railway paid. In the first place, it was based on a price of 0.5*d.* per kw-hr. which was admitted by Mr. Dawson to be below the average price the South London Elevated Railway was at present paying. In the second place, it was based on the consumption during test runs made with great care and with measuring instruments which certainly did not read too high. In the third place, the 66 watt-hours per ton-mile, being the result of test runs, allowed nothing for shunting and other unaccounted mileage. In the fourth place, the above energy consumption was measured at the train and not at the switch-cabin at which it was metered for payment, and therefore made no allowance for line losses. Under the conditions of actual

running, the gross consumption as metered for payment would be considerably in excess of the consumption at the train on test runs. In his (Mr. Hobart's) paper he had taken it as 30 per cent greater, both for the single-phase and for the continuous electricity trains. As quoted in the preceding paragraph, Mr. Dawson had indicated 85 watt-hours per ton-mile as an appropriate figure for the consumption "at the point where current is paid for." This was 29 per cent greater than his 66 watt-hours consumption at the train during test runs, and was sufficiently in accord with his (Mr. Hobart's) 30 per cent allowance.

Now as to the weight of Mr. Dawson's single-phase equipment. In Par. 69 the author showed that in his term "electrical equipment" he comprised air-compressors and governors, all cables, switch-panels, collecting devices and all mechanical structures required in connection with them, as well as all wiring and everything of a mechanical nature required in connection with the wiring or with any other part of the electrical installation. Until Mr. Dawson produced a detailed statement of the items making up his figure of only 36 tons for the electrical equipment, he would, personally, be of the opinion that when they arrived at a common basis of comparison, his estimate of 44 tons would be seen to be the appropriate figure for the weight of the electrical equipment on the South London Elevated trains, and that it would be consistent with the basis employed for the weights of the equipments of the continuous-electricity trains.[1] In the Light Railway and Tramway Journal,[2] Mr. Dawson gave the weight of a motor-coach as 54 tons, and the weight of the complete train as 138 tons. Thus the weight of the trailer worked out at $138 - (2 \times 54) = 30$ tons, leaving $2 \times (54 - 30) = 48$ tons difference, of which he (Mr. Hobart) had taken 44 tons as representing the weight of the electrical equipment with all its accessories, and 4 tons as the extra weight of the trucks. Nevertheless, for the following comparisons he would employ Mr. Dawson's estimate of 36 tons. It was incumbent upon Mr. Dawson, however, to take an early occasion to explain how it was that each of the coach-bodies was, in the case of the motor-coaches, 4 tons heavier than the coach-body of the trailer-coach. It should be noted that

[1]Thus, as stated in Par. 69 of the paper, the weights of the Piccadilly-Tube continuous-electricity equipments were usually given out as 7.3 tons, but in his estimates he took them as 8.0 tons to provide for having an absolutely inclusive figure.

[2]June 11, 1909, p. 343.

all three coach-bodies were of identical length. Thus, although there was a weight of 8 tons in the train for which Mr. Dawson offered no explanation, he would, nevertheless, take, in the following calculations, Mr. Dawson's estimate of 36 tons in place of his own estimate of 44 tons.

As regards Mr. Dawson's claim that 6 out of the 8 motors were sufficient for the service, he (Mr. Hobart) had taken the various trains as they actually stood, and he had not considered that it would be profitable to indulge in speculations with regard to what might have been. He saw no reason to suppose that there was any more margin of capacity in the 8-motored S.L.E. train than in the 8-motored Southport train. Mr. Dawson would hardly contend that engineers having the great experience of the Allgemeine Elektricitäts Gesellschaft in single-phase work would have proposed 8 motors for his 3-coach train if 6 motors were really sufficient for the service. Mr. Dawson had asserted that 6 motors were quite sufficient to run the scheduled time with ease, and as a matter of fact, had often done so. Since they were not concerned with an equipment only quite sufficient to run the scheduled time with ease, but rather with an equipment suited to handle the service, Mr. Dawson could not conclude that his train was over-motored any more than this could be claimed for the Southport train. The margin to which Mr. Dawson alluded was no greater than was usual in electric trains. Any well-proportioned electric train would easily run a few trips with 25 per cent of the motors cut out. In this matter he had made his position clear in Pars. 71, 76 and 77. In these the author quoted from the 1908 Board of Trade returns. The returns for the year 1909 (date of publication 1910) were now available, and he found that the electrical traffic on the Southport line amounted in 1909 to 1.48 million of train-miles and to 5.24 millions of car-miles. Consequently the average figure for the cars per train was

$$\frac{5.24}{1.48} = 3.54 \text{ cars.}$$

A very large part of the traffic was conducted with four-coach trains made up of two motor-coaches and two trailers. This was one of the normal trains employed for the 30-miles-per-hour-1-stop-per-1.32-mile service.[1] On the contrary, the S.L.E. trains were practically invariably 3-coach trains. Consequently, instead of being unjust to the single-phase system he had been unjust to the

[1] Illustrated in Proc. I. Mech. E., 1909, p. 442.

continuous-electricity system in his comparison so far as regards the weight of equipment required for a given service. Consequently in the following comparisons, he would take Mr. Dawson's equipment of 36 tons as appropriate for his 138-ton train. Table 4 now became, making permissible omissions for brevity's sake, as shown in Table 33.

He would now proceed to the next stages of the calculations involved in adopting Mr. Dawson's data. The composition of the two trains would be taken as in Table 34, which also comprised further obvious steps in the comparison.

He had thus obtained the horsepower per ton appropriate to the two services. The next step related to the modifications necessary to

TABLE 33 TABLE 4 (HOBART) REVISED

	Southport Train	S.L.E. Train
Weight of train, tons	118	138
Schedule speed, mi. per hr	30	22
Energy consumption, per ton-mile, watt-hr	96	66
Energy consumption, per train-mile, kw-hr	11.3	9.12
Average input per train, kw	340	201
Efficiency of equipment, per cent	70	70
Average output from motors to axles, h.p.	319	189
Weight of electrical equipment, tons	30	36
Average output per ton of electrical equipment, h.p.	10.6	5.25

the South London Elevated train in order that it should be equal to the Southport train service. There would be required $\left(\frac{2.7}{5.25} = \right) 0.515$ ton of electrical equipment per ton weight of train. Denoting by W the total weight of the South London Elevated train when revised to be capable of performing the Southport service, we had $W = 0.515 \times W + (138 - 36)$, or 210 tons. Weight of electrical equipment = 210 − 102 = 108 tons. Average output of which

TABLE 34 COMPOSITION OF SOUTHPORT AND S.L.E. TRAINS

	Southport Train	S.L.E. Train
Electrical equipment, tons	30	36
Trucks, tons	37	37
Coach bodies, tons	51	65
Total weight, tons	118	138
Percentage which the weight of the electrical equipment constitutes of the total weight of the train	25.4	26.0
Average output, h.p.	319	189
Average per ton-weight of train, h.p.	2.7	1.37

electrical equipment was capable (with reasonable margin of
rve) = 108 × 5.25 = 566 h.p. (as against the 189 h.p. which
ced for the South London Elevated service). Thus the revised
:h London Elevated train required to have 566 h.p. average
icity as against the 319 h.p. which sufficed for the normal South-
train. This was an increase of 77 per cent. While both trains
the same length of 180 feet, the South London Elevated train,
n altered to be adequate to perform the Southport service,
;hed 78 per cent (since $\frac{210}{119} = 1.87$) more than the Southport
n.

eversing the process, and adapting the Southport train to the
th London Elevated service, they had:

The South London Elevated service required per ton of total weight of train, 1.37 h.p.

Corresponding weight of equipment $\left(\frac{1.37}{1.07} =\right)$ 0.129 ton per ton-weight of train.

Complete weight of electrical equipment = 0.129 W.

Weight of Southport train exclusive of electrical equipment was 118 − 30 = 88 tons.

Therefore, W = 0.129 W + 88 = 101 tons.

Weight electrical equipment = 101 − 88 = 13 tons.

he weights of the four trains would be as shown in Table 35.
this table he had favored the single-phase system, for the
ons of electrical equipment would be carried by only two trucks,
the total weight of the trucks in the train would be less than the
tons allowed in column 2. Similarly the 37 tons allowed for
·ks in column 3 would be utterly inadequate for a 3-coach train

TABLE 35 WEIGHTS OF THE FOUR TRAINS

	Continuous Train		Single-Phase Train	
	For Southport service, tons	For S. L. E. service, tons	For Southport service, tons	For S. L. E. service, tons
ks	37	37	37	37
h bodies	51	51	65	65
rical equipment	30	13	108	36
weight	118	101	210	138

carrying 108 tons of electrical equipment. It should be noted that the somewhat great coach-body weight in the single-phase train was necessitated by the acceptance of Mr. Dawson's figure for the equipments, since the figure of 138 tons for the empty train was also Mr. Dawson's and had never been in dispute. The matter of the weight of the coach bodies was, however, a minor one and did not greatly affect the final calculations.

In Table 36 are given the corresponding costs of the above four trains.

TABLE 36 CORRESPONDING COSTS OF THE FOUR TRAINS

	Continuous Train		Single-Phase Train	
	For Southport service, £	For S. L. E. service, £	For Southport service, £	For S. L. E. service, £
Trucks	815	815	815	815
Coach bodies	4070	4070	5300	5300
Electrical equipment	3750	1630	13500	4890
Further costs	590	510	1050	890
Total costs of train	9225	7025	20565	11895
Weight of train, tons	118	101	210	138
Cost per ton	78.1	69.5	98.0	81.3

He now had the data for a revision of Table 13, which he would call Table 37.

TABLE 37 REVISION OF TABLE 13 (HOBART)

Schedule speed, mi. per hr	30		22	
Distance between stops, mi	1.32		0.88	
Equipment of train	Continuous	Single-phase	Continuous	Single-phase
Weight of train, tons	118	210	101	138
Net consumption of electricity at train in watt-hr. per ton-mile	96	96	66	66
Net consumption of electricity at train in kw-hr. per train-mile	11.3	20.2	6.7	9.1
Miles per train per annum	54,000	54,000	48,000	48,000
Net consumption per train per annum, kw-hr	610,000	1,090,000	322,000	437,000
Gross consumption per train per annum (= 1.3 × net consumption) in kw-hr	795,000	1,420,000	419,000	569,000
Cost of electricity delivered at train per kw-hr., *d*.	0.64	0.51	0.64	0.51
Total annual cost per train for electricity, £	2120	3030	1120	1210
Total annual cost per train-mile, *d*.	9.45	13.4	5.60	6.05

It must be expressly stated that these results did not represent his own conclusions. Railway officials would, in his opinion, be wrong to rely upon obtaining such low costs for electricity. While a very large consumption of electricity by a railway might, under favorable conditions as regards coal, water, wages, etc., enable it to obtain prices at the train as low as those shown in Table 37, 0.64*d.* for continuous electricity and 0.51*d.* for single-phase electricity, this was not the case at present, and for a conservative comparison with steam-locomotive working, the results in his Table 13 were the most appropriate. He had simply worked out Table 37 to meet Mr. Dawson's criticisms, to illuminate the subject in general, and to show, as would appear in Table 38, that, without accepting them in any way, but merely applying them as a matter of interest, his ultimate results were much more decidedly to the advantage of the continuous system as regards the relative costs, and that, as pointed out in the paper, the relative superiority of the continuous system increased rapidly with increasing severity of service.

Mr. Dawson wrote : "Mr. Hobart in his figures of cost of electrical energy per train-mile assumed that the electricity would cost them from 10*d.* to 15*d.* per train-mile. On the basis of the energy consumption which now existed, and at ½*d.* per unit, this figure for their service only amounted to 4.83*d.* per train-mile." In making this statement Mr. Dawson utterly misrepresented the case. The author's figure of 15*d.* was carefully stated to refer to the single-phase train when remodelled to be equal to performing the Southport service. It was only his figure of 10*d.* which Mr. Dawson should have compared with his figure of 4.83*d.* The deduction of the one from the other was simple. Mr. Dawson took the hypothetical, and as yet (on his railway) unattained, price of 0.50*d.* per kw-hr. Substituting the more appropriate price of 0.72*d.* (at the train), we had

$$\frac{0.72}{0.50} \times 4.83 = 6.95d. \text{ per train-mile}$$

The author took a net consumption of 79 watt-hours per ton-mile, which was a figure of recognized appropriateness for the service in question, while Mr. Dawson took 66 watt-hours per ton-mile, a figure which he (Mr. Hobart) could not admit.

$$\frac{79}{66} \times 6.95 = 8.30d. \text{ per train-mile}$$

He added 30 per cent to the test-run consumption to bring it up to the

conditions of actual routine service. Mr. Dawson made no allowance whatsoever on this score

$$1.30 \times 8.30 = 10.8d.$$ per train-mile

Notwithstanding hypothetical estimates, he was satisfied that the actual cost to the L. B. & S. C. Railway was at present much nearer to his figure of 10.2*d.* per train-mile than to Mr. Dawson's value of 4.83*d.* per train-mile.

Table 38 gave the equivalent of Tables 14 and 15.

TABLE 38 EQUIVALENT OF TABLES 14 AND 15 (HOBART), REVISED

Schedule speed, mi. per hr.	30		22	
Distance between stops, mi.	1.32		0.88	
System	Continuous	Single-phase	Continuous	Single-phase
Total annual cost per train for electricity, £	2120	3020	1120	1310
Annual charges for capital depreciation, repairs and renewals per train, £	1380	3080	1050	1600
Sum of above two annual outlays per train, £	3500	6100	2170	2900
Miles per train per annum	54000	54000	48000	48000
Cost per train-mile for electricity, *d.*	9.45	13.4	5.60	6.55
Annual charges for rolling stock per train-mile, *d.*	6.14	13.7	5.25	8.00
Sum of above two outlays per train-mile, *d.*	15.59	27.1	10.85	14.45
Amount by which the single-phase train costs more per train-mile than the continuous-electricity train, *d.*	11.5		3.6	

Mr. Dawson seemed to have somewhat misunderstood the subject of the paper. It was a comparison between systems, and whilst certain data had been taken from the South London Elevated line, it was not his (Mr. Hobart's) intention that the reasoning should be regarded as an analysis of the working costs on that line. So long as any particular assumption was fair to the single-phase system it was immaterial, from his point of view, whether or not it exactly corresponded with the conditions existing on the South London Elevated line. However, there were data available from which a very good idea of the commercial results of the South London Elevated electrification scheme could be deduced, and these results indicated in the clearest possible manner that the railway company had as yet little cause for satisfaction in their venture. He proposed to demonstrate this by deducing from information which was perfectly authoritative in its essential and important particulars, a rough

approximation to the profit and loss account of the electrified lines for the first six months of working.

In February 1910, the Chairman stated that in the two months of December 1909 and January 1910 during which the electric line had been open, the number of passengers had increased by 440,536, or by 63 per cent, as compared with the corresponding months of the preceding year. Since 440,536 was 63 per cent of 700,000, it was seen that the total number of passengers during these 62 days was 1,141,000. At the meeting in July 1910, the increase due to electrification was given as $1\frac{3}{4}$ millions for six months. This works out at a total of approximately $(3 \times 700{,}000) + 1{,}750{,}000 = 3{,}850{,}000$ passengers for the six months, an increase of 83 per cent as compared with steam working, and as against an increase of 63 per cent for the first two months of electrical working. In order to carry these passengers, however, it would seem on the authority of the time table that as many as 217,270 train-miles were run, giving on the average, $\frac{3{,}850{,}000}{217{,}279} = 17.7$, or say 18, passengers carried per train-mile run. The number of trains as per the amended time table for January 1 to June 30, 1910, worked out as follows:

26 Sundays, 62 trains each (both directions)....	1612 train journeys
1 Good Friday, 62 trains (both directions).....	62 train journeys
26 Saturdays, 159 trains each (both directions).	4134 train journeys
128 ordinary week-days, 152 hours(both directions	19,456 train journeys
	25,264 train journeys

25,264 train journeys of 8.6 mi.....217,270 train-miles

On page 50 of the report of the London Traffic Branch of the Board of Trade for 1909, Sir George Gibb was quoted as follows: "The average receipt per passenger carried by the nine urban railways in London only ranges between 1.45*d.* on the North London Railway which is the lowest, and 2.03*d.* on the Central London Railway which is the highest of the group."

It was not stated which the other lines considered were, or whether the South London Elevated Railway was included, but an inspection of the fare list on this line would indicate that the average fare did not exceed the highest of the above limits; in fact, it was very lenient to the South London Elevated Railway to take it so high as 2*d.* per passenger. It might be noted that the most expensive weekly ticket was 2*s.* per 12 trips or 2*d.* per passenger. Thus the receipts were certainly not more than $18 \times 2 = 36d.$ per train-mile, and it

was much more probable that they were appreciably below this figure. In the following analysis he proposed to take the receipts at 36*d.* per train-mile.

In the Board of Trade Railway returns for 1909[1], the average receipts on the passenger trains of the London, Brighton & South Coast Railway were given as 56.7*d.* per train-mile. It might be said, however, that since the electric trains comprised only three coaches they might be cheaper to work than the average steam-train. On the contrary, it appeared that they would not even be as cheap to work. The 1909 Board of Trade returns showed[2] that the average London, Brighton & South Coast train cost 39.87*d.* per mile to run. This 39.87*d.* was made up as follows:

	d.
a Locomotive power	11.80
b Repairs and renewals of rolling stock	3.18
c Maintenance of way, traffic charges, general charges, rates, taxes, and miscellaneous charges	24.89
	39.87

The third group of items in the above table was fairly independent of system.

In the case of the electric trains, weighing 138 tons, let Mr. Dawson's figure be accepted for the amount of electricity to be paid for as being 85 watt-hr. per ton-mile.[3] As they were not concerned with future prices, and as the lowest authentic and definite figure they had any warrant for accepting was the 0.75*d.* per kw-hr. given in Mr. Forbes' evidence, they might take the price of power for the six months under consideration as at least

$$0.085 \times 138 \times 0.75 = 8.8d.$$ per train-mile.

Mr. Chapman, late chief engineer of the Underground Electric Railways Company, of London, had arrived[4] at the figure of 0.6*d.* per car-mile for the maintenance and repairs of the rolling stock of the Underground Electric Railways Company. But his normal trains averaged only $\frac{6}{7} = 0.86$ of a motor and accompanying equipment per coach, as against $\frac{8}{3} = 2.66$ motors per coach on the South

[1]Board of Trade, 1909, p. 45.
[2]Board of Trade, 1909, p. 49.
[3]Philip Dawson in The Light Railway and Tramway Journal, p. 19.
[4]See F. W. Carter's paper, Electrification of Suburban Railways, Par. 17.

London Elevated Railway. Thus the South London Elevated Railway had $\frac{2.66}{0.86} = 3.1$ times as many motors per coach. Moreover, the South London Elevated coaches were larger, their upholstery was more elaborate, and they were of a type more difficult to keep clean. Taking these factors into account, then even making no allowance for the fact that each single-phase motor and its accompanying equipment was much more expensive than the continuous-electricity apparatus on Mr. Chapman's line, it was entirely out of the question that when the time arrived that the outlay for repairs and renewals had become steady, this outlay would be less than 1.5*d.* per car-mile,[1] or 4.5*d.* per train-mile. The drivers' wages might be taken as 1*d.* per mile at least. The maintenance and renewal of line conductors, painting of gantries, renewal of insulators, bonds, etc., would certainly not be less than 2.5*d.* per train-mile. In addition to this, as shown in Mr. Carter's paper (Par. 15), the extra capital involved in electrifying the 8.6 miles of route burdened the scheme to the extent of 6.4*d.* per train-mile on the initial service of 64 trains per day in each direction, and to the extent of 5.5*d.* per train-mile for the service for the six months under consideration, assuming that the original estimates had not been exceeded. Thus they had:

	d. per train-mile
Electricity	8.8
Repairs and renewals of equipment	4.5
Drivers' wages	1.0
Maintenance of conductor system	2.5
Capital burden	5.5
Total	22.3

This might be compared with the corresponding costs with steam working, which were made up of 11.80*d.* for locomotive power plus

[1] In this connection considerable interest attached to the statement of the chairman at the last February meeting of the London, Tilbury & Southend Railway concerning electrical renewals. His statement was: The total cost of maintenance and renewals of the service works out at 2.573 pence per car-mile for the half year. This possibly included maintenance of track conductors, but even then was higher than the author was assuming above for the South London Elevated Railway, although the London, Tilbury & Southend trains were substantially the same as Mr. Chapman's District Railway trains, and there was no reason to suppose that the maintenance of the expensive overhead-conductor system of the South London Elevated Railway would be nearly as low as that of the comparatively inexpensive third and fourth rails of the London, Tilbury & Southend Railway. (See Railway News, February 5, 1910, p. 152.)

3.18*d.* for repairs and renewals of rolling stock, the sum of these two items being 11.80 + 3.18 = 14.98*d.* Thus the single-phase electric service cost, 22.3 − 15.0 = 7.3 more per train-mile, while the receipts were 56.7 − 36.0 = 20.7 less per train-mile, than for the average steam-train. Moreover, if to the running costs there were added for maintenance of way, traffic charges, general charges, rates, taxes and miscellaneous charges, the same average figure as was found for steam operation, namely, 24.9*d.*, the total expenditure per train-mile became 22.3 + 24.9 = 47.2*d.* as against not more than 36*d.* receipts. Of course the traffic charges, general charges, rates, taxes, etc., would not be increased in proportion to the increased train-mileage, so that the 11.2*d.* per train-mile excess of expenditure over receipts corresponded to a fictitious rather than a real loss, but the deficit was altogether too large to be accounted for (much less turned to profit) by these considerations, and there was no doubt whatever that the first six months' working of the electric trains had resulted in a very considerable actual loss to the railway company.

This discussion was based entirely on present working of the South London Elevated Railway. It was not suggested or intended to suggest that it should be regarded as a full statement of the economic effects of electrification, nor was it suggested that the average figures he had quoted from the Board of Trade Returns necessarily applied to the suburban area. It was probable that with the extension of the system, the average cost of electricity per kw-hr. would ultimately be reduced below the figure given by Mr. Forbes as the minimum London, Brighton & South Coast contract price, and the extension would doubtless somewhat reduce the burden of capitalization. On the other hand, the other three items of expenditure, repairs and renewals of equipments, drivers' wages, maintenance of conductor system, would in all probability be greater than as above estimated. Thus while the above discussion was not presented as proving the failure of electrification on the system employed in the South London Elevated Railway, it might certainly be taken as proving that the time for elation had not yet arrived. The present economic position would seem such as ought not to be longer concealed from shareholders. Whilst the extension of the system might cover up the shortcomings of its inception and even ultimately result in a qualified success, it would take a high order of wisdom in the future handling of the situation to save it from being a distinct disaster from the shareholders' standpoint. While a squandered quarter of a million was a driblet to a railway, similar

recklessness with a couple of million or more would not be without its ultimate effects on dividends. The difference in capital burden and running costs between the continuous-electricity system and the single-phase system, which would probably prove to be at least 6*d*. per train-mile in the case of the South London Elevated line, might easily make all the difference between ultimate commercial success and failure in the London, Brighton & South Coast electrification. The interest of shareholders appeared to be too easily lulled by general statements of increased traffic. Mr. Pomeroy stated in his paper (Par. 191) that considerable increase of business is necessary before profit begins to be shown. The London, Brighton & South Coast Railway was merely shown to have secured an increased business, but nothing had been disclosed of a nature to indicate that the increased business was remotely sufficient to pay for the cost of obtaining it.

With regard to Mr. Williams' suggestion that the author should extend his paper to bring the 1200-volt continuous-electricity system into the comparison, he would have been glad to do so, were it not that his contribution to the discussion had already unavoidably exceeded the customary limits. But by showing that the single-phase system was greatly inferior to the 600-volt continuous-electricity system for the severe Southport service, and that it was also still considerably inferior even for the exceptionally easy South London Elevated service, he had by inference shown that the 1200-volt continuous-electricity system would be found superior over a still greater range. In other words, wherever electricity could compete with steam-locomotive methods, the 600-volt continuous-electricity system was nearly always more economical than the single-phase system; but there were ultimately reached classes of conditions where, owing usually to the sparseness of the service, the steam-locomotive afforded the most economical means of propelling trains. The appropriateness of electrical methods extended further in this direction with the 1200-volt than with the 600-volt system.[1] Still further in the scale, the single-phase system excelled in economy the 1200-volt (or possibly even the 2400-volt) continuous-electricity system, but by the time that point in the scale was reached, the steam-locomotive, so far as related to present developments, usually afforded the true economic solution.

[1] An aggregate length of route of about 800 miles was at present operating with or in hand for high-pressure continuous-electricity equipment.

Mr. Williams and also Mr. Parshall had touched upon an interesting point in calling attention to the low power-factor to the single-phase system. Mr. Dawson put the power-factor of his load at 81 per cent[2] and he doubted if it was any better than this figure. Putting on top of this the inferiority and greater cost of the single-phase generators in the supply station, and the one-third greater cost for conductors for transmitting a given amount of single-phase power at a given power-factor and at a given pressure between conductors, then it was seen that so soon as the engineers of electricity-supply undertakings realized more clearly than they yet did the effect on their costs of these three points in which single-phase was seriously at a disadvantage as compared with three-phase for transmission, their price for single-phase electricity at 0.8 power-factor, would go up by fully 15 per cent as compared with their price for three-phase electricity at unity power-factor, if the load-factor were the same in both cases. While polyphase electricity at unity power-factor and for a good load-factor, could, in bulk, and with reasonable prices for coal and water, be supplied to a considerable distance at 0.5*d.* per kw-hr. delivered, and still yield a slight profit, this could not be said of single-phase electricity for the same load-factor and of only 0.80 power-factor. Although he had not introduced this point of difference into his comparisons, since he desired under the circumstances to favor the single-phase proposition as far as was reasonable, he would probably have been nearer the truth in debiting the single-phase system with at least a 10 per cent greater relative price than he did, owing to these further disadvantages as compared with a system employing polyphase generation and transmission at unity power-factor.

He had left Mr. Dalziel's criticism to the last, but had had the intention to deal consecutively with each of the points he raised. Unfortunately it had been absolutely necessary to deal very precisely with the points raised by Mr. Scott and Mr. Dawson, and he did not care to take up more space than would suffice to deal in a general way with certain of the points raised by Mr. Dalziel. It was plain from the paper which Mr. Dalziel read before the Institution of Civil Engineers last winter that it was the Siemens trains and not the Westinghouse train on which Mr. Dalziel desired to focus attention. Much less information was given with regard to the Westinghouse train. One could only conclude that the Westing-

[2]Proc. Inst.C.E., vol. 179, pt. 1, p. 128.

house train had proved less satisfactory than the Siemens train. Therefore he considered it desirable that he should take the Siemens train as the basis for his comparison. In the tender for the electrical equipments for the Heysham road, the clause on which much emphasis was laid was to the effect that the motors would be required to have a temperature rise not exceeding 90 deg. fahr. (50 deg. cent.) after hauling the 3-coach train for six double trips from Heysham to Morecambe, Morecambe to Lancaster and return, to such a time table as to be fairly interpreted as that stated in his paper, namely 31 miles per hr. and a stop about every 4 miles. The equipments would not be much good if they could not do other work than this, but this was the most normal and usual task required of them by the specification. The fundamental plan of his paper had been to take normal trains doing their normal and usual work, and to assume that they were appropriately designed for that work. Any speculations as to the possibilities of modifications would lead to hopeless confusion.

Mr. Dalziel need have no misgivings as to the accuracy of this figure of 93 watt-hr. per ton-mile for the Piccadilly train. It was a strictly appropriate figure for the conditions in question. Mr. Dalziel's figure of 63 watt-hr. per ton-mile for the schedule in question would be utterly insufficient and would, with reasonable acceleration and breaking, correspond to about 100 per cent efficiency of the equipment on the train as against an actual efficiency of some 70 per cent. On the occasion of his contribution to the discussion on Mr. Dalziel's paper at the Institution of Civil Engineers last winter, he (Mr. Hobart) endeavored to make clear the distinction between the ability of an equipment to run for an hour or so with a given load and the ability to maintain the service uninterruptedly for, say, 18 hours per day. It would appear that Mr. Dalziel had run his equipment intermittently with loads considerably in excess of the 31 miles per hr., one-stop-per-4-miles conditions, but he did not understand that Mr. Dalziel had explicitly asserted that his loads had been more than 6 h.p. per ton of equipment when averaged over any considerable number of hours, not excluding lay-overs, and there was no likelihood that he would make this assertion.

In conclusion, he would say that he agreed with Mr. Aspinall that if, when, and wherever the single-phase system was developed to the point of being useful on main-line railroads, there would be no appreciable difficulties in using it in such cases in conjunction with the use of the continuous-electricity system. It was precisely

in this matter of flexibility that electrical methods excelled. Almost any desired transformation with respect to the precise kind of electricity could readily be effected, and usually at high efficiency and reasonable capital cost. Thus the case for proceeding with a scheme of rigorous standardization was by no means urgent. In so far, however, as there should be any need for standardisation, since the most extensive appropriate field for electrification was much more economically filled by the continuous than by the single-phase system, the former system was the one which should be standardized.

W. B. POTTER said that it was recognized that the conditions assumed for a comparison of direct-current and alternating-current systems on an interurban railway, were such that the comparative economy of steam and electricity might be debated, but that they were within the scope of a number of electric railways in America. A single-track railroad 100 miles long with cars on one-hour headway, a schedule speed of 33 mi. per hr. and stops 3 mi. apart, should presumably be favorable to the single-phase equipment, and was for that reason selected for analysis.

For Mr. Hobart's information it might be stated that largely on account of snow it was the accepted practice in American interurban service to use four-motor equipments to ensure maintenance of schedule. The equipments considered for both direct-current and alternating-current had four motors with natural ventilation. Furthermore, the single-phase cars were also equipped for direct-current operation, a condition which was very generally required in American practice. There were about 35 interurban railways in the United States operating at 1200 volts direct-current or single-phase, and of these, 22 were required to operate on 600-volt direct-current circuits. As affecting the traffic, it would have been advantageous for a number of the other roads to have been equipped for 600-volt operation in their terminal cities.

As to total cost of operation and maintenance, the electrification items given under annual operation and maintenance (Table 21), were generally found to be about 45 per cent of the total operating costs for 600 volts. The annual costs for the 600-volt system would therefore be about as follows:

Annual operation and maintenance	$95,800
Other operating costs	115,200
Total operating costs	$211,000
Annual fixed charges	81,200
Total annual cost	$292,200

or approximately $0.27 per car-mile, which was a reasonable figure for American interurban service of the character considered.

Mr. Hobart was right, he said, in saying that the power consumption and maximum speed selected was high for a theoretical time table of 33-mi. per hr. with one stop in 3 miles on a straight and level track with best conditions. It should be borne in mind that the road considered was single track. There would therefore be two meeting points per hour. Allowing 1 minute for each meet and 20 seconds for each stop, the possible schedule speed on a straight and level track was calculated to be 36.6 mi. per hr. with a power consumption of 90 watt-hours per ton-mile not including electric power for heaters. This margin of 10 per cent in schedule time was a customary allowance to insure the proper performance of the time table, taking into account the variations in voltage, slow-downs for curves and incidental delays. Though the car was performing the high schedule speed while running, it was delayed a suffient amount of time so that the time table schedule only was performed. The power required was determined by the lower schedule speed and the energy by the higher.

Mr. Scott stated that six cars in commission would be sufficient for the proposed service. The minimum number which would be used to maintain the proposed time table would be seven cars. Mr. Scott further said that he thought all would agree on one thing, namely that the figures given in the paper were excessive for the number of cars selected for the assumed service. By reference to Table 17, it would be seen that 18 cars were selected for the single-phase system. The number of cars was large for the theoretical time table, but was proportionally not greater than the average number owned by existing single-phase roads based on the average daily mileage of all cars.

Table 39 gave information from the time tables of 12 single-phase roads in America. The first line referred to the conditions assumed in the paper in Table 17, while the other twelve lines referred to the individual railroads.

Par. 225 qualified these requirements as follows:

> Outside of economy in capital expenditure, and economy and convenience in operation by steam or electricity, it matters not whether each locomotive and car and the apparatus upon them differ from every other locomotive and car in size or details of construction, so long as the constructions are operative and the materials employed are used within safe limits.

In those countries having railways of comparatively light construction with many heavy gradients and where speeds were moderate, the three-phase system, by reason of the less weight and lower cost of three-phase locomotives, would have advantages which might lead to its adoption. It was to be noted, however, that it would be practicable to operate locomotives and cars fitted with single-phase apparatus upon lines especially equipped for three-phase operation; that was to say, one of the overhead trolley wires could supply a single-phase current to one or more motors, or the two overhead wires could be used, one supplying single-phase current to one motor and the second overhead wire, current to a second motor; in other words, it would be possible to have a portion of the lines of a country fitted with single-phase apparatus and other portions fitted with three-phase apparatus so that there could be interchange of traffic, provided the three fundamental requirements mentioned were adhered to in the construction of the generating and transmission apparatus.

The author recognized the generousness of the references made to his paper and the value of the remarks of the several speakers. He felt, however, that the impressions gained by Mr. Parshall from his comparatively short study of the use of single-phase apparatus on the New York, New Haven & Hartford Railroad must undergo a very radical change as a result of a further study of the operations of this particular installation.

In speaking of the equipment of the Central London Railway and the large number of sub-stations, Mr. Parshall appeared not to have mentioned the important fact that the Board of Trade requirement limiting the drop in the earth return circuit to seven volts, results from the electrolytic effect of stray continuous currents upon metals in close proximity to such circuits, whereas with the alternating current the electrolytic action was most generally considered a negligible quantity, so that without a doubt the Board of Trade authorities would in due course so modify their requirements that the single-phase or three-phase alternating-current apparatus could be installed under conditions more in accord with actual necessities. It must not be overlooked

that study and practical experience had rendered the use of alternating currents of very high voltage highly advantageous commercially with due regard to safety requirements.

The author had been asked why several single-phase installations in the United States had been displaced by the substitution therefor, by the same manufacturers, of a 600 or 1200-volt direct-current system. He had been informed and believed that such an abandonment of single-phase apparatus was due primarily to the fact that the motors employed had not been thoroughly developed, and furthermore, as it was necessary to operate the cars over direct-current city lines in a number of those cases, which placed certain limitations on the design of the motors and necessitated certain complications in the control apparatus, the wisdom of the original adoption of single-phase apparatus was open to serious question.

In one case, one-half of the route was over a direct-current line and in another case the cars were operated in different portions of the route by a single-phase trolley, by an ordinary direct-current trolley, and by a direct-current double trolley (the second wire being used instead of the track return), and it was further desired to operate on another portion of the line having direct-current underground conduits. Obviously, in such cases, the necessity of operation with complicated equipments over the direct-current lines introduced difficulties which might go far to overbalance the advantages of the use of the single-phase system on the cross-country lines. As the result, the delays and expensive maintenance charges caused dissatisfaction on the part of the railway companies, and the replacement of the apparatus resulted. In all of these cases, motor cars only were involved, there being no locomotives, and therefore these changes had little or no bearing on steam railway electrification.

These substitutions were quite unimportant as compared with the decision of the New York, New Haven & Hartford Railroad Company which had employed single-phase apparatus on the largest scale and in the most severe service, to operate with single-phase apparatus all of the trains, passenger and freight, through the Hoosac tunnel, to extend the single-phase equipment to its six-track Harlem River Branch for the operation of its freight as well as its passenger service, thus operating all trains west of Stamford by electricity, and to equip the New York, West Chester & Boston Railroad, which had physical connection with the New Haven road at New Rochelle, with single-phase 11,000-volt apparatus.

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In conclusion the author again earnestly recommended to the atten-

tion of those charged with the responsibility of directing init installations the need of determining the system which admitted the largest extensions of railway electrification, in recognition of t conditions which will arise in the future. The fact that it might difficult to reach a decision did not lessen the importance of hav a single system, nor would the likelihood that diversity might be actual outcome in some cases make the confusion less unfortun when the problem of common operation arose in the future. T conditions should be clearly understood, and the initial work sho not be undertaken without recognizing the larger future probl and the costly consequences of errors made now.

No. 1294

MEETINGS OCTOBER-DECEMBER

NEW YORK MEETING, OCTOBER 11

At the New York monthly meeting of the Society on October 11, a paper was presented by Frank B. Gilbreth, on Fires: Effects on Building Materials and Permanent Elimination. The paper was discussed by J. P. H. Perry, H. deB. Parsons, Ira H. Woolson and F. A. Waldron, the lantern being used by each to illustrate his remarks; also by P. H. Bevier and Wm. D. Grier. Written discussion was offered by E. E. Seyfert, Chas. T. Main and C. A. P. Turner.

SAN FRANCISCO MEETING, OCTOBER 14

At a meeting in San Francisco, held on October 14, the members of the Society resident in San Francisco and the vicinity gathered to effect an organization. Calvin W. Rice, Secretary, went out from New York to represent the Council at this meeting and to assist in these initial steps. A. M. Hunt was elected Chairman of the Committee on Meetings in San Francisco, and T. W. Ransom, Secretary. W. F. Durand, E. C. Jones and Thomas Morrin were chosen to constitute the Executive Committee.

ST. LOUIS MEETING, OCTOBER 15

At the meeting of the Society in St. Louis on October 15, the Engineers Club participating, a paper by Frank B. Gilbreth, on Fires: Effects on Building Materials and Permanent Elimination, was presented. W. H. Bryan presided and in the absence of the author the paper was presented by E. L. Ohle, Mem. Am. Soc. M. E., and was discussed by E. D. Meier, A. A. Aegerter, James Waterworth, H. W. Hibbard, W. H. Bryan, R. W. Maxton, G. R. Wadleigh, A. B. Greensfelder, J. E. Conzelman and Geo. M. Peek. Written discussions by Chas. T. Main, C. A. P. Turner and I. H. Woolson were read.

BOSTON MEETING, OCTOBER 19

A meeting of the Society in Boston on October 19 was conduct by the Boston Society of Civil Engineers, the Boston Section of t American Institute of Electrical Engineers coöperating. Pr Thomas A. Jaggar presented a paper on An Account of the Destru tion of Carthego, Costa Rico, by Earthquake, on May 4, 1910, a Chas. M. Spofford, Member of the Boston Society, and Frank Gilbreth, Mem. Am. Soc. M. E., discussed the effects of earthqua on different classes of structures. By means of lantern slides number of views of the destruction caused by earthquakes in Carth and elsewhere were shown.

NEW YORK MEETING, NOVEMBER 9

At the New York monthly meeting on November 9, the first h of the session was devoted to a paper on The Rotary Kiln, by E Soper, read by R. C. Carpenter in the absence of the author. T paper was discussed by R. K. Meade, W. S. Landis, H. E. Bu and Mr. Ruggles.

Following this, an address upon the Panama Canal was made Charles Whiting Baker, who discussed the methods used in ca ing on the construction work at the canal, illustrating his talk w pictures taken at the time of his visit in 1909, as a membe the engineering commission appointed by President Roosevelt. Baker said that the Canal is to be regarded as a problem in tr portation as, in fact, practically everything is a problem of this t Things are not made or manufactured, but one sort of materi merely taken from one place and put into another. The diggi the canal is easier and simpler than the carrying away to a dist of several miles of the material dug out by the great steam sho which remove 5 cu. yd. at a movement. But even this is cheaper to pile the material on the high banks of the canal.

A greater problem, even, than this one of the removal of ea the caring for the big working force of 30,000 laborers and skilled workmen, comprising over a score of different nationa and all social grades. Moreover, everything needed to buil canal—tools, machines, cars, locomotives, lumber,—and to comfortable the great force of men and their families, had brought 2000 miles.

The engineers at the Canal had taken up many of their bu

not through choice, but necessity, for conditions had to be met as they arose, and they should rather be honored than criticised for their achievements, by none more than by their professional brethren.

BOSTON MEETING, NOVEMBER 10

A monthly meeting of the Society in Boston was held on November 10, with the Boston Society of Civil Engineers and the Boston Section of the American Institute of Electrical Engineers coöperating. After a brief business session, a topical discussion on Smoke Abatement was opened by Dwight T. Randall, Mem.Am.Soc.M.E., who made a statement of the case as applied to New England. He was followed by E. G. Bailey, Frederick H. Keys, Charles H Manning, Henry Bartlett, George H. Barrus, John T. Hawkins and C. H. Bigelow.

ST. LOUIS MEETING, NOVEMBER 12

A meeting of the Society in St. Louis was held on November 12. At the conclusion of dinner, the meeting was called to order by Wm, H. Bryan, Chairman of the Committee on Meetings in St. Louis On motion the present committee, consisting of Wm. H. Bryan M. L. Holman, E. L. Ohle, F. E. Bausch and R. H. Tait, was re-elected for one year, subject to the approval of the Committee on Meetings of the Society and of the Engineers Club of St. Louis, with whom meetings are usually held. The method heretofore followed in the conduct of local meetings was approved, and it was voted that for the present the meetings continue to be conducted jointly with the Engineers Club of St. Louis. A general discussion of local business followed.

BOSTON MEETING, DECEMBER 16

A meeting of the Society in Boston was held on December 16, with the coöperation of the Boston Society of Civil Engineers and of the Boston Section of the American Institute of Electrical Engineers. After the transaction of business, Samuel B. Fowler, Mem. Am.Soc.M.E., presented his paper on the Mechanical Handling of Freight, and the various phases of the situation were discussed by D. B. Rushmore, C. W. E. Clarke, Ernest W. Day, F. W. Hodgden, R. H. Rogers, R. E. Curtis, George H. Eaton and G. T. Sampson.

SAN FRANCISCO MEETING, DECEMBER 16

The first professional meeting of the Society in San Francisco w held on December 16, with Pacific Coast Practice in the Use of Cru Petroleum as Fuel, as the subject of a topical discussion. T following brief papers were presented: Present and Future Sup of Petroleum as Fuel on the Pacific Coast, by Arthur F. L. I with the Associated Oil Company, San Francisco; Relative Hea Value of Light Oil as Compared with Heavy Oil, by J. N. Le Co Comparison of Evaporative Value of Oil and Coal, by C. F. Wie Furnace Arrangements for Using Oil as Fuel under Boilers, inclu the Subject of Air Requisite for Proper Combustion, by C Weymouth; Practice as to Size of Stacks with Oil Fuel, K. G. D Marine Use of Fuel Oil, by J. H. Hopps; Atomization of Oil: including the Subject of When and Where the Use of Compr Air is Justified or Required, by A. M. Hunt; Present Status o Manufacture of Producer Gas from Crude Oil, by E. C. J Because of the length of the papers, the general discussion deferred until the next meeting.

THE ANNUAL MEETING

The thirty-first annual meeting of the Society was held in the Engineering Societies Building, December 6 to 9, with an attendance of 633 members and 410 guests. This year the arrangements for the entertainment features of the program were in the hands of the newly-appointed Committee on Meetings of the Society in New York, Walter Rautenstranch, Chairman, and as a result of their efforts the visiting members and guests were afforded a thoroughly enjoyable time, with excursions of unusual interest. The reception given by Mr. and Mrs. Westinghouse on Thursday afternoon and the lecture by Dr. Georg Kerschensteiner were largely attended, as were the usual evening receptions, and brought out many expressions of commendation for the excellence of the arrangements.

PROGRAM

OPENING SESSION

Tuesday, December 6, 8.30 p.m., Auditorium

THE PRESIDENT'S ADDRESS

By George Westinghouse, President

ELECTION OF OFFICERS

Report of Tellers of Election of Officers and introduction of the President-elect, Col. E. D. Meier.

RECEPTION

The President and President-elect and Honorary Secretary Hutton, with their ladies, received the members and guests in the rooms of the Society. Music and refreshments followed the reception.

BUSINESS MEETING

Wednesday, December 7, 10 a.m., Auditorium

Annual business meeting. Reports of the Council, Tellers of Election of membership, standing and special committees. Amendment of charter. New business.

PROFESSIONAL SESSIONS

THE JOINT MEETING IN ENGLAND: Reports by the Honorary Secretary and the Secretary.

THE TRANSMISSION OF HEAT IN SURFACE CONDENSATION, George A. Orrok.

Discussed by W. F. M. Goss, W. D. Ennis, Wm. Kent, H. H. Suplee and Thomas C. McBride.

Wednesday, 2 p. m., Auditorium

STEAM ENGINEERING

COMBUSTION AND BOILER EFFICIENCY, Edw. A. Uehling.

Discussed by C. H. Bathgate, W. D. Ennis, Wm. Kent, D. S. Jacobus, J. C. Parker, A. W. K. Billings and H. C. Abell.

AUTOMATIC CONTROL OF CONDENSING WATER, B. Viola.

Discussed by C. H. Baker, G. Dinkle, W. C. Shallcross and E. D. Dreyfus.

TEST OF A 10,000-KW. STEAM TURBINE, Sam. L. Napthaly.

TEST OF A 9000-KW. TURBO-GENERATOR SET, F. H. Varney.

Both papers discussed by J. W. Lawrence, D. S. Jacobus, I. E. Moultrop, G. A. Orrok, E. D. Dreyfus, F. Hodgkinson, R. J. S. Pigott, W. L. R. Emmet and W. L. Waters.

NOTES ON THE VALUE OF NAPIER'S COEFFICIENT WITH SUPERHEATED STEAM, Isaac Harter, Jr.

Discussed by H. E. Longwell and R. C. H. Heck.

REUNION

Wednesday, 9 p.m., Hotel Astor

A reunion of the membership of New York in honor of the newly elected officers and visiting members of the Society, their ladies and guests was held at the Hotel Astor. Dancing and refreshments followed the reception.

PROFESSIONAL SESSIONS

Thursday, December 8, 10 a.m., Auditorium

A NEW THEORY OF BELT DRIVING, Selby Haar.

Discussed by Carl G. Barth, G. N. VanDerhoef, H. G. Reist, A. F. Nagle, H. Emerson, G. I. Rockwood, F. W. Taylor, T. M. Phetteplace and Wm. Kent.

A GRAPHICAL METHOD FOR CALCULATING STRESSES IN A CONNECTING ROD, Winslow H. Herschel.

Discussed by L. L. Willard and C. G. Lanza.

OPERATING CONDITIONS OF PASSENGER ELEVATORS, Reginald P. Bolton.

Discussed by Emanuel Hollander.

MODERN SHOE MANUFACTURE, M. B. Kaven and J. B. Hadaway.

Discussed by E. J. Quinlan, E. Robinson and R. H. Long.

Thursday, 2 p.m., Auditorium

MACHINE SHOP

THE FIELD FOR GRINDING, C. H. Norton.
PRECISION GRINDING, W. A. Viall.
MODERN GRINDING METHODS, B. M. W. Hanson.

Discussed by W. L. Bryant, H. A. Richmond, G. M. Jeppson, Henry Hess, H. M. Leland, A. L. DeLeeuw, Oberlin Smith, O. Junggren and J. W. Cole.

Thursday, 2 p.m., Sixth Floor

GAS POWER SECTION

Business meeting. Reports of committees and election of officers.
Chairman's Address: GAS POWER DEVELOPMENT, James R. Bibbins.

FIRST LARGE GAS ENGINE INSTALLATION IN AMERICAN STEEL WORKS, E. P. Coleman.

Discussed by Joseph Morgan, W. A. Bole, G. A. Orrok, E. A. Uehling, C. W. Baker, E. D. Dreyfus, E. E. Kiger, G. C. Conlee and Louis Dolley.

NOTES ON A HEAVY-DUTY GAS PRODUCER, Nisbet Latta.

Discussed by W. B. Chapman, W. E. Winship and L. B. Lent.

RECEPTION

Thursday, 4 to 6 p.m., Hotel St. Regis

Mr. and Mrs. Westinghouse received the members of the Society and their guests.

ADDRESS

Thursday, 8.15 p.m., Auditorium

The National Society for the Promotion of Industrial Education, the American Institute of Mining Engineers, The American Society of Mechanical Engineers, and the American Institute of Electrical Engineers coöperating.

INDUSTRIAL CONTINUATION SCHOOLS OF MUNICH, Georg Kerschensteiner, Superintendent of Schools, Munich. Illustrated by lantern slides.

Friday, December 9, Morning and Afternoon

Excursions to points of engineering interest. Fred H. Colvin, Chairman, Committee on Excursions.

ORGANIZATION OF COMMITTEES

EXECUTIVE COMMITTEE

COMMITTEE ON MEETINGS

W. E. HALL, *Chairman*

W. H. BRYAN — C. E. LUCKE — H. DE B. PARSONS

L. R. POMEROY

MEETINGS OF THE SOCIETY IN NEW YORK

WALTER RAUTENSTRAUCH, *Chairman*

F. A. WALDRON, *Treasurer*

F. H. COLVIN — EDW. VAN WINKLE — R. V. WRIGHT

Sub-Committee on Finance

F. A. WALDRON, *Chairman*

:N	J. W. LIEB, JR.	W. H. MARSHALL
:K	F. R. LOW	F. J. MILLER
LL	W. M. MCFARLAND	H. R. TOWNE

COMMITTEE ON ENTERTAINMENT

EDW. VAN WINKLE, *Chairman*

Sub-Committee on President's Reception

C. W. AIKEN, *Chairman*

N	S. D. COLLETT	ALFRED NOBLE
:R	W. C. DICKERMAN	W. P. PRESSINGER
OSSOM	L. G. FRENCH	R. W. PRYOR, JR.
TOL	W. E. HALL	B. V. SWENSON
KNER	H. A. HEY	I. H. WOOLSON
EIGH	H. B. LANGE	R. V. WRIGHT
EIGH	J. W. LIEB, JR.	E. W. WYATT
	F. J. MILLER	

Sub-Committee on Reunion

R. S. ALLYN, *Chairman*

:N	C. R. PLACE	E. A. STEVENS
T	C. R. RICHARDS	A. F. STILLMAN
ZE	E. W. RUTHERFORD	J. S. THOMSON
CH	F. A. SCHEFFLER	REGINALD TRAUTSCHOLD
WOOD	W. I. SLICHTER	EDW. VAN WINKLE
ON	E. A. SPERRY	F. A. WALDRON

COMMITTEE ON EXCURSIONS

FRED H. COLVIN, *Chairman*

RD	W. T. DONNELLY	S. B. REDFIELD
RISTIE	W. J. KAUP	E. H. WHITE
:KE	L. B. LENT	W. B. YEREANCE
	JOHN PLATT	

ACQUAINTANCESHIP COMMITTEE

Tuesday

R. V. WRIGHT, *Chairman*

Afternoon	Evening
ON, *Sub-Chairman*	F. V. HENSHAW, *Sub-Chairman*
HM	H. R. COBLEIGH
LER	HARRINGTON EMERSON
Y	C. W. OBERT
EAD	L. A. SHEPARD

Wednesday

Morning	Afternoon
F. E. Rogers, *Sub-Chairman*	C. W. Baker, *Sub-Chairman*
W. T. Donnelly	H. D. Gordon
F. A. Errington	S. H. Libby
Arthur Falkenau	J. W. Nelson
W. R. Hulbert	H. G. Torrey

Thursday

Morning	Afternoon
H. L. Gantt, *Sub-Chairman*	Jesse M. Smith, *Sub-Chairman*
R. E. Fox, Jr.	E. H. Berry
L. B. Lent	F. A. Halsey
E. F. Muther	J. M. B. Scheele
N. B. Payne	F. A. Scheffler
G. B. Preston	Hosea Webster

Evening

F. R. Low, *Sub-Chairman*

L. P. Alford — E. B. Katte
George Dinkel — E. H. Neff
Geo. A. Orrok

BUREAU OF INFORMATION

Walter Rautenstrauch, *Chairman*

LADIES' RECEPTION COMMITTEE

Mrs. Herbert Grey Torrey, *Chairman*

Mrs. H. C. Abell	Mrs. G. S. Humphrey	Mrs. E. N. Sanderson
Mrs. L. P. Alford	Mrs. C. W. Hunt	Miss M. R. Scheffler
Mrs. G. H. Barbour	Mrs. F. R. Hutton	Mrs. Jesse M. Smith
Mrs. A. R. Baylis	Mrs. P. C. Idell	Mrs. J. P. Sneddon
Mrs. E. H. Berry	Mrs. D. S. Jacobus	Miss Jean Sneddon
Mrs. Wm. H. Boehm	Mrs. J. A. Kinkead	Mrs. H. H. Suplee
Mrs. R. P. Bolton	Mrs. G. L. Knight	Mrs. Edw. Van Winkle
Mrs. Edward Ciardi	Mrs. J. W. Lieb, Jr.	Mrs. Geo. Westinghouse
Mrs. H. E. Cooke	Mrs. Fred R. Low	Mrs. H. H. Westinghouse
Mrs. H. Emerson	The Misses Meier	Mrs. S. E. Whitaker
Mrs. G. L. Fowler	Mrs. C. W. Obert	Dr. Lucy O. Wight
Mrs. F. J. Gubelman	Mrs. G. A. Orrok	Mrs. W. H. Wiley
Mrs. Willis E. Hall	Miss Eugenie Price	Mrs. Jas. Edw. Wilson
Mrs. F. A. Halsey	Mrs. C. W. Rice	Mrs. I. H. Woolson
Mrs. H. F. Holloway		Mrs. W. F. Zimmermann

Chairman Committees for the Several Days

Tuesday afternoon.....Mrs. John W. Lieb, Jr.
Wednesday morning.....Mrs. Edward Van Winkle
Wednesday afternoon.....Mrs. Jesse M. Smith
Thursday morning.....Mrs. C. W. Hunt
Friday morning.....Mrs. James Edward Wilson

Executive Committee

MRS. HERBERT GRAY TORREY, *Chairman*		
. HUMPHREY	MRS. J. W. LIEB, JR.	MRS. GEO. WESTINGHOUSE
'. HUNT	MRS. JESSE M. SMITH	MRS. JAS. EDW. WILSON
O. WIGHT	MRS. EDW. VAN WINKLE	MRS. I. H. WOOLSON

Ladies' Guides

DR. LUCY O. WIGHT, *Chairman*		
⁞. ABELL	MRS. EDWARD CIARDI	MRS. C. W. OBERT
ALFORD	MRS. G. S. HUMPHREY	MRS. J. P. SNEDDON
:. BOEHM	MRS. G. L. KNIGHT	MRS. S. E. WHITAKER

ACCOUNT OF THE MEETING

nnual Meeting was formally opened on Tuesday evening President's reception. As on the year previous, this was ıe rooms of the Society, which are well adapted to a gathering ınd and are most attractive with their new furnishings and ns. At the session in the auditorium the presidential address by the retiring President, George Westinghouse, which com- ı account of the conception and development of the air- ıich has constituted so large a part of the life-work of Mr. ıouse and has made possible the wonderful advance through- orld resulting from modern transportation facilities. Follow- ddress, George A. Orrok for the Tellers of Election of Officers ɔd the names of the new officers for the coming year, g of E. D. Meier, President; George M. Brill, E. M. Herr, ughan, Vice-Presidents; D. F. Crawford, E. B. Katte, Stanley , Jr., Managers. F. R. Hutton and Alex. C. Humphreys the President-elect to the platform, Dr. Humphreys intro- im with a few words of appreciation, to which he responded s:

ɔiate fully your kind confidence in bestowing on me the highest ch can come to an American engineer, and the grave responsibil- eptance imposes. But it is one of the glories of our noble profession es great opportunities for service to our fellowmen; and duty well own best reward. This is strongly impressed on me by the simple, ɔry your retiring President has just read to us, but which commemo- ɔf the most valuable services rendered to the whole civilized world e of engineering.

ɔering that his life work came after his youthful patriotism had ervice in our old navy, I will remind you that while life lasts the old are just as ready for duty as the tars; still we two are perhaps the boys of the early sixties on whom you can confer this honor.

At the reception in the rooms the members and guests were receiv by the President and Mrs. Westinghouse, President-elect Meier, th Misses Meier, Honorary Secretary Hutton and Mrs. Hutton, and the Secretary. Music and refreshments added to the pleasure of the gathering.

Business Meeting, Wednesday Morning, December 7

The first professional session opened with the annual busine meeting, President E. D. Meier in the chair. The Secretary read t report of the Tellers of Election to Membership, including 131 a plicants for membership and 16 for advance in grade. This l appears in the Annual Report of the Council.

Worcester R. Warner, reporting on the status of the Land a Building Fund, said that $88,920.03 had been received to date, le ing $85,765.03 to be raised. Mr. Warner supplemented his recita the figures by an account of the efforts of the Committee in se ing contributions. One firm which had previously contributed $1 added an equal amount and a check for $500 from the presid the company. There were other instances of generous contribut and certain of them, though of considerably smaller amount, c from members who must have made a personal sacrifice. M however, have not contributed at all and still others have sent c butions which it is hoped will be supplemented by addit amounts.

The President then announced that the discovery had rec been made of a slight discrepancy in the charter under whic Society now acts, relating to the date of the Annual Meeting. matter was referred to the Committee on Constitution and By- who had drawn up a certificate to be voted upon by ballot at the ing and to be filed with the Secretary of State to the effect tha intended to amend the present articles of incorporation and to them conform with the Constitution. Jesse M. Smith rea certificate for the Committee and moved the adoption of the f ing resolution, which was seconded by W. F. M. Goss.

Whereas, The annual meeting of this Society has been for many yea on the first Tuesday of December of each year; and

Whereas, The Constitution and By-Laws of the Society provide t annual meeting shall begin on the first Tuesday of December in each ye

Whereas, The Constitution and By-Laws provide for, and the ele officers has been, for many years past, by letter-ballot, cast prior to ginning of the said annual meeting; and

Whereas, Upon the consolidation of this Society with the Mechanical Engineers' Library Association in 1907, the agreement of consolidation inadvertently provided that the annual election should be held on the second Tuesday of December in each year; and

Whereas, The Society has, in each year since that date, had it annual election by letter-ballot prior to the beginning of the said annual meeting, and has begun its annual meeting on the first Tuesday of December in each year, both in accordance with the Constitution and By-Laws of the Society; and it is the desire of the members that the annual meeting and annual election should be held in accordance with the said Constitutions and By-Laws;

Now, therefore, be it resolved, That the time of beginning the annual meeting of this Society and the time and manner of holding the annual election of officers of the Society, be changed from the second Tuesday of December in each year, and be held at such time and in such manner as shall be provided in the Constitution and By-Laws of the Society.

After the resolution had been debated the Chairman appointed tellers of the vote, for whom I. E. Moultrop announced that the resolution had been duly carried.

F. R. Hutton called attention to the need in this country of an adequate museum of engineering in which could be recorded the developments in engineering processes through models and apparatus, referring to the museum at Munich as an example of what could be accomplished. Several others followed emphasizing in their remarks the benefits to be derived from such museums and referring to similar institutions in Europe, especially that at Munich. President E. D. Meier stated that over $4,000,000 had been received to erect a building for the exhibits contained in the Munich museum, and this in the small country of Bavaria. Attention was called to the efforts of the Smithsonian Institution in this direction. The Secretary stated that a room in the Engineering Societies Building was available for the beginning of such a museum.

Frank B. Gilbreth said, that as it was in order to make suggestions, he wished the Society would consider the advisability of a central bureau for the collection and preservation of data relating to scientific management. The work involved in the obtaining of original data seems an unnecessary expense and there should be a central bureau on the same plan as the government bureaus, where the results of investigations of others can be placed at the disposal of any who apply. C. E. Lucke of the Committee on Meetings said that his Committee had this particular question under consideration with plans relating to it and had recommended the appointment of a special committee to take up all these relating subjects.

President E. D. Meier then referred to the address of the retiring President, George Westinghouse, given on the previous evening, in which was told the history of the great invention which had covered the entire world and made the name of Westinghouse known wherever an iron wheel rolls on a steel rail. Many a man considers himself an inventor when he brings out an idea. That is the first step and the next is to embody the idea in practice. Here difficulties arise such as Mr. Westinghouse referred to so easily, almost playfully, but which were actually very grave. If he had not been a man of powerful physique, he would not have been able to carry through his undertaking. The great inventor is not the one who has the first idea, as the public sometimes imagines, but one who works continuously through years of time for the perfection and application of the idea.

That is essentially the work of the engineer, and engineers can be proud of their contribution and of the fact that the whole progress of the world for the past fifty years has depended on the engineer in one way or another.

James M. Dodge followed with a motion of a vote of thanks to Mr. Westinghouse for his admirable and interesting address, which was unanimously carried by a rising vote.

The President then referred to the sad announcement which he had made on the previous evening, of the sudden death of William H. Bryan, Chairman of the Committee on Meetings of the Society in St. Louis, who had risen to distinction in the engineering world through his own energy and ability. He was a personal friend with a wide acquaintance in the Society and had recently passed through a strenuous competitive examination for the appointment as Chief Engineer for the School Board of the City of Chicago, as a result of which he had won the appointment.

L. R. Pomeroy of the Committee on Meetings of the Society, of which Mr. Bryan was also a member, offered the following resolution of condolence which was unanimously passed:

Resolved: That the members of The American Society of Mechanical Engineers assembled in Annual Meeting, having heard of the death of their fellow-member, William H. Bryan, hereby express their sense of loss, appreciation of his services to the Society, and sympathy for his family.

It is further

Resolved: That a copy of this resolution be sent to his family.

John A. Brashear asked for suggestions from members of the Society regarding the Carnegie Technical Schools at Pittsburgh. The

original intention of Mr. Carnegie was that the schools should be for the education of young men and young women who worked for their living, but that the institution had grown until it had taken a high rank among technical institutions. There are now 2250 students with a waiting list of 2500. The schools have the support of trade unions which have recently contributed $35,000 towards the work.

Dr. Brashear said also that he had recently had a quarter of a million dollars placed in his hands by a citizen of Pittsburgh for the betterment of teaching and teachers in the public schools, and that when members of the Society went to Pittsburgh they should not think of its smoke alone, but of the efforts which were there being made to give workers a chance to earn a livelihood, to learn something and to be helped to positions of usefulness. One of the most beautiful things in this world is to help our fellowmen and only by this means will our work be well done.

The President asked that any who had suggestions to make regarding the place for the Spring Meeting should express their preference to members of the Committee on Meetings while in attendance at the Annual Meeting, and said that it would be agreeable to many if the next one could be held in the West, in view of the fact that the last two Spring Meetings had been held in the East.

James M. Dodge, Chairman of the Committee on Public Relations, said that whereas other committees of the Society were working for the development of the Society itself, his committee had been appointed to look after the welfare of the profession at large. The work was but just beginning, the committee would gladly receive suggestions, and hoped to report substantial progress at the next meeting. One question under consideration was that of licensing engineers. It is not a simple problem, owing to the fact that there are both graduate engineers, so-called, and those who are graduated from the school of experience.

Dr. Hutton followed with an invitation to visit the Museum of Safety in the Engineering Societies Building.

Professional Session, Wednesday Morning

Following the business meeting the Honorary Secretary and the Secretary presented reports of the Joint Meeting of the Society with The Institution of Mechanical Engineers, held in Birmingham and London in July 1910. These reports are published elsewhere in this volume of Transactions.

They were followed by George A. Orrok whc
The Transmission of Heat in Surface Conden
results of 771 heat transmission tests made
ser tube under the various conditions of co
conclusions drawn by the author from these a
statement of the law of heat transmission
with reference to mean temperature differen
water, effect of air leakage and effect of the ma
is made. The paper was discussed by W. F.
Wm. Kent, H. H. Suplee and Thomas C. Mcl

PROFESSIONAL SESSION, WEDNESDA

The session of Wednesday afternoon was
Steam Engineering.

The first paper presented was by Edw. A. 1
and Boiler Efficiency, and maintained that
steam generator depended on conditions far
steam engine or dynamo. The importance of
of CO_2 in the flue gas and the stack tempera
trolling factors in steam boiler economy, were
The paper was discussed by C. H. Bathgat
Kent, D. S. Jacobus, John C. Parker, A. W.
Abell.

This was followed by a paper on the Aut
densing Water, by B. Viola which gave
barometric counter-current condensers in co
pans, and was illustrated with many recordi
operation. This was discussed by Geo. Dir
cross and E. D. Dreyfus.

Two accounts of turbine tests were then pre
kw. Steam Turbine, by Sam. L. Naphtaly
steam economy tests on a unit at the plant of
pany, San Francisco, with a description of n
application of correction factors to meet sp
the other on a 9000-kw. Turbo-Generator
with a description of tests and results. The
W. Lawrence, D. S. Jacobus, I. E. Moultrop,
Dreyfus, Francis Hodgkinson, R. J. S. Pigott
W. L. Waters.

The final paper of the session was by Isa

Notes on the Value of Napier's Coefficient with Superheated Steam, comprising a series of determinations of the value of the coefficient for steam at pressures closely averaging 160 lb. per sq. in. abs., and for various degrees of superheat ranging approximately between 50 and 200 deg. This was discussed by Henry E. Longwell and R. C. H. Heck.

Reunion, Wednesday Evening

A reunion of the membership of New York in honor of the newly-elected officers and visiting members of the Society, their ladies and guests, was held at the Hotel Astor on Wednesday evening, December 8. Dancing was begun at nine o'clock, those who did not care to participate occupying boxes, and supper was served during the intermission. The occasion, like those of a similar nature of previous years, was greatly enjoyed by all, and added much by the renewal of old acquaintances and the making of new ones, to the social side of the convention, emphasizing as it did the general feeling of friendliness which was so evident throughout the entire series of meetings.

Professional Session, Thursday Morning

At the Thursday morning session four papers were read upon miscellaneous subjects. The first, A New Theory of Belt Driving, by Selby Haar, presented a theory of the process by which a belt transmits power and a study of the losses occurring in the belt while under load, so that its efficiency may be determined. The paper was discussed by Carl G. Barth, Geo. N. Van Derhoef, H. G. Reist, A. F. Nagle, Harrington Emerson, F. W. Taylor, T. M. Phetteplace, George I. Rockwood and Wm. Kent.

A Graphical Method for Calculating Stresses in a Connecting Rod, by W. H. Herschel, followed, which dealt with a method for finding stresses at any point of a rod of any shape. This was discussed by L. L. Willard and C. G. Lanza.

Operating Conditions of Passenger Elevators was presented by Reginald Pelham Bolton, who directed attention to the effects upon elevator work and economy of the passenger movement and traffic by reducing the period of actual motion and by increasing the time occupied in the operations of starting and stopping. It was discussed by Emmanuel Hollander.

The fourth paper presented was upon Modern Shoe Manufacture, by M. B. Kaven and J. B. Hadaway. This treated of the ancient

methods of covering the feet, the old-time shoe shop in which each workman was taught to make the entire shoe, the making of the hand-sewed shoe, the advent of the sole-sewing machines, the direct means of revolutionizing the shoe industry, and subsequent inventions substituted for hand work which finally led to the building of the modern shoe factory. Mr. Hadaway who presented the paper illustrated his remarks with some samples of the welt shoe which he had brought with him. The paper was discussed by Edwin J. Quinlan, Edward Robinson and R. H. Long.

Machine Shop Session, Thursday Afternoon

Three papers on Grinding were presented on Thursday afternoon at a Machine Shop Session, the first, The Field for Grinding, by C. H. Norton, dealing with the new idea of grinding as quick cutting, rapid reduction of stock, accuracy and economy, with modern machines, modern wheels that cut and do not abrade, and a knowledge of the science of the process, which, the author believes, is worthy of systematic coöperation on the part of the engineer. The second paper, Precision Grinding, by W. H. Viall, discussed grinding as an art, especially as related to the manufacturer's problems where not only the nicest accuracy is obtained, but where the rate of production is an important consideration. Modern Grinding Methods, by B. M. W. Hanson, was the last of these papers, and described recent developments in grinding machines for cylindrical work and plane surfaces, with an account of new features of the cylindrical grinder whereby the work is sized automatically, and illustrations of pieces ground on a surface grinder, using a cupped wheel on a vertical spindle which has a high rate of production. These papers were discussed by W. L. Bryant, A. L. DeLeeuw, H. A. Richmond, Geo. M. Jeppson, Henry Hess, Henry M. Leland, Oberlin Smith, O. Junggren and J. Wendell Cole.

Gas Power Session, Thursday Afternoon

At the meeting of the Gas Power Section, also held on Thursday afternoon, the annual address of the Chairman was made by James Rowland Bibbins, on Gas Power Development. Reports were received from committees, the Membership Committee reporting a steady and normal growth of high quality.

The Literature Committee had already published its results from time to time in The Journal, but expected even better results during the year before the Section.

The Research Committee announced that its work had been turned over to the Research Committee of the Society. The Installations Committee reported progress and the Standardization Committee, having completed its work, was discharged. The Committee on Plant Operations did not present a report in writing, but I. E. Moultrop, Chairman, announced that data from three or four producer-gas power plants were expected shortly.

The Committee on Elections announced the following officers elected: Chairman, R. H. Fernald; Member of the Executive Committee, C. J. Davidson. The Chairman-elect was then escorted to the chair by Professor Breckenridge.

Two professional papers were also presented at this session, the first that by the late E. P. Coleman, on the First Large Gas-Engine Installation in American Steel Works, presented by E. E. Kiger, which described in a very thorough-going manner an installation made in the Lackawanna Steel Company with which Mr. Coleman was connected. From the viewpoints of continuity and reliability of service the installation was considered successful, and the economy of heat consumption was considerably in excess of that usual with compound steam engines. The paper was discussed by Joseph Morgan, Wm. A. Bole, George A. Orrok, Edw. A. Uehling, Charles Whiting Baker, E. D. Dreyfus, E. E. Kiger, George G. Conlee and Louis Doelling.

A paper by Nisbet Latta, entitled Notes on a Heavy-Duty Gas Producer, was then presented, in which the author called attention to the recent development of the heavy-duty gas engine and to the fact that the gas producer had not been developed of proper size and type to accompany these large units. Recent experiments on pulverized coal and air in the proportions required to burn the carbon to CO were also described. The paper was discussed by W. B. Chapman, W. E. Winship and L. B. Lent.

Thursday Afternoon

On Thursday afternoon Mr. and Mrs. Westinghouse received the members and guests of the Society at the Hotel St. Regis from four to six o'clock. The delightful hospitality of the host and hostess with which the Society has had opportunity on previous occasions to

become acquainted, made this occasion one of the most enjoyable social events of the Annual Meeting, and it was very largely attended, affording an opportunity to extend to Mr. and Mrs. Westinghouse a personal greeting.

Lecture, Thursday Evening

The concluding gathering of the Annual Meeting was on Thursday evening, when an illustrated lecture was given by Dr. Georg Kerschensteiner, Superintendent of the Industrial Continuation Schools of Munich. This address was a noteworthy addition to the attractive lectures which have been given at each of the recent Annual Meetings. Dr. Kerschensteiner has not only achieved marked distinction through his original and effective methods for industrial training but he is an entertaining speaker, and in presenting the subject used a remarkable collection of slides from views showing classes at work in the varied lines of industry in which the students of Munich are given practical instruction. These not only include the more familiar occupations, such as work in the machine shops, foundry, pattern shop, etc., but a great variety of miscellaneous occupations ranging from the artistic to the most utilitarian, such as the supply of food and the manufature of common implements and utensils. The Society was able to enjoy this lecture through the courtesy of the National Society for the Promotion of Industrial Education, who had arranged for the address and by whom the meeting was held, The American Society of Mechanical Engineers, the American Institute of Electrical Engineers and the American Institute of Mining Engineers coöperating.

Excursions

A very fine program of excursions, sufficiently varied in their nature to meet all tastes, had been arranged by the committee in charge, F. H. Colvin, Chairman, and to these Friday, December 9, was entirely devoted. Many availed themselves of the opportunity to visit the New York Public Library at Fifth Avenue and 42d Street, W. W. Christie acting as guide. The building which will not be opened to the public until May 1911 is, however, practically complete as to its interior decorations, with the exception of pictures and furniture, and a very good idea was gained of the appearance which it will present. The visitors were especially interested in the

very fine marbles and woods as well as other materials which have been employed in its construction, and in the workmanship which is to be seen throughout the building, presenting a finished result which may be favorably compared with other public buildings throughout the United States. The various automatic devices for the speedy delivery of books to the reading room, the wilderness of steel shelves in the stack rooms, and the printing and binding machines, were also interesting features.

A party of twenty-five took advantage of the invitation to visit the plant of Nelson Goodyear, Inc., Brooklyn, N. Y., to witness the process of oxy-acetylene welding. The party was conducted by E. H. White and was shown the new type of generator and the torches used by this company. Demonstrations of welding and cutting metals were made, after which there was a demonstration by Mr. André Beltzer of the welding and soldering of aluminum by the use of a new flux for this purpose.

About a dozen members visited the Hudson and Manhattan Power House in Jersey City, under the guidance of W. B. Yereance, where they inspected the generating plant for the Hudson River tubes, known as the McAdoo tubes, a trip made possible through the courtesy of Mr. G. McAdoo. They were met at the power house by Chief Engineer Sage who personally conducted the visitors through the plant and explained the different features and the reasons for their adoption by those in charge. Some of the members of his staff had also been detailed to answer individual questions or to explain features in which any one might be especially interested.

A party of sixty were conveyed by special car to the works of the Pond Machine Tool Company at Plainfield, N. J., under the guidance of W. L. Clark, where several of the recently developed reversing motor planers were in operation and various tests were made for the benefit of the visitors. Other special machines as well as the regular processes proved of much interest and appreciation was expressed on all sides of the interesting visit. Through the courtesy of the company luncheon was served at the plant, and a special car conveyed the visitors to the city.

A party of twenty under the guidance of L. P. Alford visited the Thompson-Lovelace Aeroplane factory at Fort George, New York City, and this proved to be one of the most interesting excursions. The machine used by Moissant in his flight from Paris to London was on exhibition, completely assembled, as was also another machine for Moissant in process of erection. Various engines and parts of aeroplanes under construction were shown the visitors.

The excursion party to the yard of the John N. Robins Company, Erie Basin, Brooklyn, though not large was composed of those especially interested in the application of electricity to this class of work, particularly of the high tension, 6600-volt motors to the driving of air compressors and the pumping of basin dry docks by direct connected 6600-volt motors driving 30-in. centrifugal pumps. The large machine shop and boiler shop were also visited and the floating dry docks inspected, the new floating dry dock with steel wings and wooden pontoons coming in for particular attention.

A party conducted by S. B. Redfield spent the afternoon on Friday in the Spring Street Telephone Exchange and in the Long Distance Exchange on Cortlandt Street. The visitors were given an opportunity to see the work of the training school for telephone operators, which graduates 40 operators a week for the supply of the New York exchanges, and were shown the operation of the switchboards in the main room where 200 operators are in constant attendance. The procedure in securing a long distance call and in keeping track of the time and of the charges, and plans under way for securing even quicker service than is now obtained, were explained in detail by the representatives of the telephone company who accompanied the party.

Several of the members also visited the Navy Yard in Brooklyn.

In addition to the excursions which were participated in on Friday, a number of invitations had been received of which the members were at liberty to take advantage any time during the meeting. These included the Metropolitan Building, where Mr. Charles S. Bavier, chief engineer, received the visitors, the Interborough Power House, the Hill Publishing Company, the Waterside Power Plant of the New York Edison Company, Sims Magneto Company at Watsessing, N. J., the National Lead Company in Brooklyn, and the high-pressure fire-pumping stations of the Board of Water Supply of New York.

A party of the ladies who attended the Annual Meeting visited the Franco-American Food Company's factory in Jersey City on Wednesday morning and were escorted through this model plant by a special conductor. On Friday afternoon a trip was made to the Colgate factory in Jersey City which was also much enjoyed.

Every possible courtesy was extended to the visiting party at all these excursions and much appreciation was expressed to those who made the trips possible by throwing open their works to the Society. Material aid was rendered by the Information Bureau located in the foyer of the Engineering Societies Building.

Entertainment Features

As has been the custom for several years past, a number of the ladies resident in and about New York formed a Reception Committee under the Chairmanship of Mrs. Herbert Gray Torrey, and added much to the social side of the convention by their entertainment of the visiting ladies and members. Tea was served on Tuesday and Wednesday afternoons, Mrs. John W. Lieb, Jr., acting as hostess on the former occasion and Mrs. Jesse M. Smith at the latter. A Guides' Committee, Dr. Lucy O. Wight, Chairman, conducted parties to points of interest about the city, including the shops and hotels.

No. 1295

PRESIDENTIAL ADDRESS

By George Westinghouse, Pittsburgh, Pa.

President of the Society, 1910

ar ago I was honored by my election to the presidency of The an Society of Mechanical Engineers. In accepting office, I ed an apprehension that other duties of an onerous character prevent a fulfillment of your reasonable expectations, and I at when all is summed up, you will agree that such an apprehen- as well founded. I desire at once to express a sense of my ion to my associates for their helpfulness and consideration ng me partly to discharge my duties. Although my time for ciety's work has been very limited, I have had many occa- o observe how efficiently the splendid organization which con- our affairs has performed the various duties involved in the oment and management of an engineering society.

chief event of the year was the Joint Meeting of The Institu- Mechanical Engineers with our Society in Birmingham and 1. From all sides have come evidences of the success of those gs and of the great benefit of their deliberations to engineering. lcome extended by our brother society to those of our Society re present exceeded in cordiality and completeness the expec- of those who knew that there would be a warm and full- reception, and nothing was lacking in the perfection of ments for the meetings and for the comfort and pleasure of nbers and their ladies.

ese days, the effects of such international meetings and inter- s of good-will cannot fail to be lasting, especially in promot- se relations which stand for the advancement of science and ce, as well as those broader international relationships which wards the conservation of peace between all countries.

ldress delivered at the Annual Meeting, New York, 1910, of The N Society of Mechanical Engineers.

Of almost equal importance was the joint meeting of members of the engineering societies in Boston held on January 21, brought about by a member of our Society, Professor Hollis, of Harvard University. On this occasion about four hundred members of the engineering societies were present, including eight presidents of engineering societies or institutions, besides prominent members of many others, including architectural and scientific societies closely identified with the work of engineers.

Under the well-defined policy of your Council and officials, the members of our Society in Boston, St. Louis and San Francisco have been encouraged to hold important local meetings, and in this manner to bring the widely scattered members of the Society into more intimate relations with each other and with our affairs in general, and it is the purpose to extend our efforts in this direction as rapidly as circumstances may indicate.

My contributions to the discussions of matters of interest to our Society have been a short address, appropriate to the occasion, at the joint meeting of engineers in Boston, in which I laid stress upon the desirability of establishing, by coöperation between all engineering societies, such general standards in the construction of electrical and mechanical apparatus as would tend to reduce cost, increase efficiency, and lessen our difficulties.

In a more carefully prepared address, presented at the Joint Meeting in England, I urged the importance of an early decision on the part of those interested as to uniformity in the essential features involved in the electrification of railways. The discussion of this paper emphasized the necessity for early action on the recommendations made in regard to the selection of standards to meet the very few essential requirements.

As often happens in the discussion of a complex problem, some of the speakers misinterpreted my address and concluded that the paper specifically recommended the adoption of one particular system out of several well-known systems as a universal standard, whereas my specific recommendations were stated as follows:

"The additional fundamental requirements for electrically operated railways are:

f A supply of electricity of uniform quality as to voltage and periodicity.

g Conductors to convey this electricity so uniformly located with reference to the rails that, without change of any kind, an electrically fitted locomotive or car of any con-

pany can collect its supply of current when upon the lines of other companies.

h Uniform apparatus for control of electric supply whereby two or more electrically fitted locomotives or cars from different lines can be operated together from one locomotive or car.

"Outside of economy in capital expenditure and economy and convenience in operation by steam or electricity, it matters not whether each locomotive and car and the apparatus upon them differ from every other locomotive and car in size or details of construction, so long as the constructions are operative and the materials employed are used within safe limits."[1]

The selection of a system embodying these fundamental requirements would leave to manufacturers and inventors the same latitude for development and improvement in the construction of railway electrical machinery as has always existed with reference to steam-operated railways, where the fundamental requirements were: a standard gage of track, standard couplings of cars, and standard braking and signalling apparatus. To appreciate this observation, one has only to contrast the locomotive of twenty years ago with the mammoth Mallet compound locomotives which are now being introduced, or the freight car of ten tons capacity with the modern steel car of fifty tons capacity.

I cannot impress too strongly upon the members of this Society the great importance of lending their aid to bring about such an early decision in regard to the standards to be adopted in the electrification of railways as will insure to the traveling public the benefit of this method of transportation at the earliest possible moment and on an advantageous basis to the railways, which will be required, even under the most favorable circumstances, to expend vast sums of money in changing from steam to electric operation.

'It has been suggested to me that it would interest the members of the Society to have a short account of the conception and development of the air-brake, to form an authoritative statement for the records of the Society, and as I believe I am chiefly indebted to my work in developing the air brake and introducing it upon railways for the honors you have conferred upon me, I have pleasure in complying with this suggestion, especially as a statement of the conception and development of the air brake will supplement what I have heretofore said in regard to the benefits to be derived from the standardization of mechanical devices.

[1] Trans. Am. Soc. M. E., vol. 32, p. 948.

To deal comprehensively with a subject which involves an experience of nearly forty-five years would require much more of your time than should be taken on this occasion. I will, however, present as briefly as possible some of the salient points.

My first idea of braking apparatus to be applied to all of the cars of a train came to me in this way: a train upon which I was a passenger between Schenectady and Troy in 1866 was delayed a couple of hours due to a collision between two freight trains. The loss of time and the inconvenience arising from it suggested that if the engineers of those trains had had some means of applying brakes to all of the wheels of their trains, the accident in question might have been avoided and the time of my fellow-passengers and myself might have been saved.

The first idea which came into my mind, which I afterwards found had been in the minds of many others, was to connect the brake levers of each car to its draft-gear so that an application of the brakes to the locomotive, which would cause the cars to close up toward the engine, would thereby apply a braking force through the couplers and levers to the wheels of each car. Although the crudeness of this idea became apparent upon an attempt to devise an apparatus to carry the scheme into effect, nevertheless the idea of applying power brakes to a train was firmly planted in my mind.

Shortly afterwards, while I was in Chicago, the Superintendent of the Chicago, Burlington & Quincy Railroad, Mr. A. N. Towne, invited me to inspect what was then considered an ideal passenger train, namely the Aurora Accommodation. I accepted this invitation and while looking over the train, which was fitted with a chain brake, I was introduced by Mr. Towne to Mr. Ambler, the inventor of that brake. The Ambler brake, as was explained to me, consisted of a windlass on the locomotive which could be revolved by pressing a grooved wheel against the flange of the driving-wheel to wind up a chain which extended beneath the entire train over a series of rollers attached to the brake levers of each car and so arranged that the tightening of the chain caused the brake-levers to move and thereby apply the brake shoes to the wheels. I ventured to say to Mr. Ambler that I had been working upon a brake myself, but was immediately informed by him that there was no use working upon the brake problem, because he had devised the only feasible plan, which was fully protected by patents. Mr. Ambler's opinion and advice, however, proved to be an incentive to a more energetic pursuit of the subject.

a improvement on Mr. Ambler's plan, I considered the use of cylinder to be placed under the locomotive, the piston of this r to be so connected to the chain that it could be drawn tight application of steam from the locomotive boiler with a force could be more accurately controlled than was possible with adlass arrangement. A short study of this idea showed that it be impossible to have a cylinder long enough to operate a rake upon more than four or five cars, whereas trains of ten elve passenger cars were frequently run upon the important s.

next thought was the placing of a steam cylinder under each h a pipe connection extended from the locomotive beneath ler and under each car, with flexible connections of some sort n thought out, so that steam could be transmitted from the tive through the train pipe to all of the cylinders; but, as in the the attempt to improve the chain brake, it required but little ith some experimentation to disclose the fact that it would ssible, even in warm weather, successfully to work the brakes number of cars by means of steam transmitted from the tive boiler through pipes to brake cylinders.

ly after I had reached this conclusion, I was induced by a of young women who came into my father's works to sub- or a monthly paper, and in a very early number, probably the e I received, there was an account of the tunneling of Mount by machinery driven by compressed air conveyed through of pipes, the then depth of that tunnel. This account of the ompressed air instantly indicated that brake apparatus of the ntemplated for operation by steam could be operated by means pressed air upon any length of train, and I thereupon began to develop drawings of apparatus suitable for the purpose 1867 promptly filed a caveat in the United States Patent o protect the invention. In the meantime, I had removed henectady to Pittsburgh, where I met Mr. Ralph Baggaley, dertook to defray the cost of constructing the apparatus to make a demonstration.

hat time no compressed-air apparatus of importance had my knowledge been put in operation. The apparatus needed demonstration was, however, laboriously constructed in a e shop in Pittsburgh, being finally completed in the summer or utumn of 1868. This apparatus consisted of an air pump, a servoir into which air was to be compressed for the locomo-

tive equipment, and four or five cylinders such as were to be put under the cars, with the necessary piping, all so arranged that their operation as upon a train could be observed. Railway officials of the Pennsylvania and Panhandle railroads were then invited to inspect the apparatus and witness its operation. As a result, the Superintendent of what was then known as the Panhandle Railroad, Mr. W. W. Card, offered to put the Steubenville accommodation train at my disposal to enable me to make a practical demonstration. The apparatus exhibited was removed from the shop and applied to this train, which consisted of a locomotive and four cars. Upon its first run after the apparatus was attached to the train, the engineer, Daniel Tate, on emerging from the tunnel near the Union Station in Pittsburgh, saw a horse and wagon standing upon the track. The instantaneous application of the air brakes prevented what might have been a serious accident, and the value of this invention was thus quickly proven and the air brake started upon a most useful and successful career.

Prior to the construction and practical test of the air brake, I had opportunities while traveling to present the subject to numerous railway officials and to endeavor to secure their coöperation in the development of the apparatus. None of those approached appeared to have faith in the idea, though I afterwards found that the acquaintances made and the many discussions I had had with railway people were of great advantage in the introduction of the air brake upon the railways with which they were connected.

I suppose many persons present have heard or read the story of an alleged interview between Commodore Vanderbilt and myself about the application of air brakes to the New York Central. The story as told seems to have appealed to the imagination of many people. As a matter of fact, there is no foundation whatever for that story. From the moment when the practicability of air brakes was demonstrated to the present hour, there has been nothing but satisfaction and pleasure in being associated with an invention which has contributed so much to the safety and comfort of travelers and so greatly to the prosperity of railways.

In the development and introduction of the air brake, I was controlled by the apparent fact that the apparatus would have to be uniform upon all cars to provide for the convenient change of the composition of trains. It also was most obvious, in view of the crying demand for some better means for stopping trains, that some power brake would inevitably be universally applied to all of the cars

and engines upon all railways. These ideas naturally involved a further one, namely, the importance of having all of the brake apparatus made by one company, so as to insure absolute uniformity and consequent interchangeability, and this led to the formation of the Westinghouse Air Brake Company early in 1869.

The essential parts of the air brake as first applied were:

a An air-pump driven by a steam engine receiving its supply from the boiler of the locomotive.

b A main reservoir on the locomotive into which air was compressed to about 60 or 70 lb. pressure per sq. in.

c A pipe leading from the reservoir to a valve mechanism convenient to the engineer.

d Brake cylinders for the tender and each car.

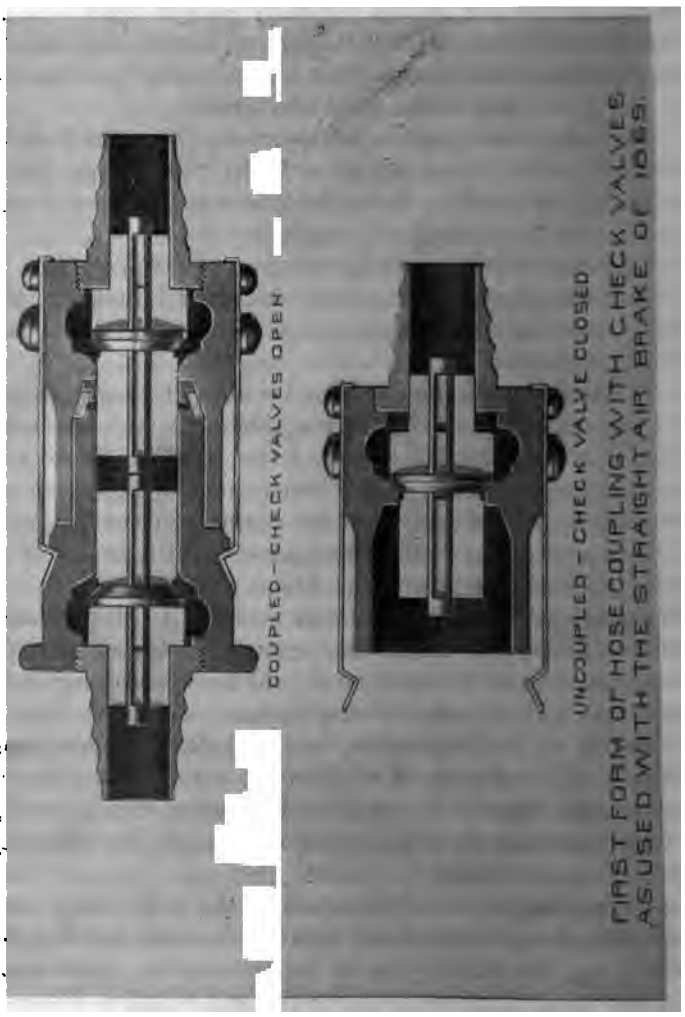
e A line of pipe leading from the brake valve under the tender and all of the cars, with a pipe connection to each brake cylinder.

f Flexible hose connections between the cars provided with couplings having valves which were automatically opened when the two parts of the couplings were joined and automatically closed when the couplings were separated so that the valve of the coupling at the end of the train was always closed and prevented the escape of air when introduced into the brake pipe.

The piston of each cylinder was attached to the ordinary hand-brake lever in such a manner that when the piston was thrust outward by the admission of compressed air, the brakes were applied. When the engineer had occasion to stop his train, he admitted the air from the reservoir on the locomotive into the brake cylinders through the train pipe. The pistons of all cylinders were, it was then supposed, simultaneously moved to set all of the brakes with a force depending upon the amount of air admitted through the valve under the control of the engineer.

To release the brakes, the handle of the brake valve was moved so as to cut off communication with the reservoir and then to open a passage from the brake pipe to the atmosphere, permitting the air which had been admitted to the pipes and cylinders to escape.

The success of the apparatus upon the first train was followed by an application of an equipment to a train of six cars on the Pennsylvania Railroad, and in September 1869, this train was placed at the disposal of the Association of Master Mechanics representing numerous railways, which association was then in session at Pittsburgh.



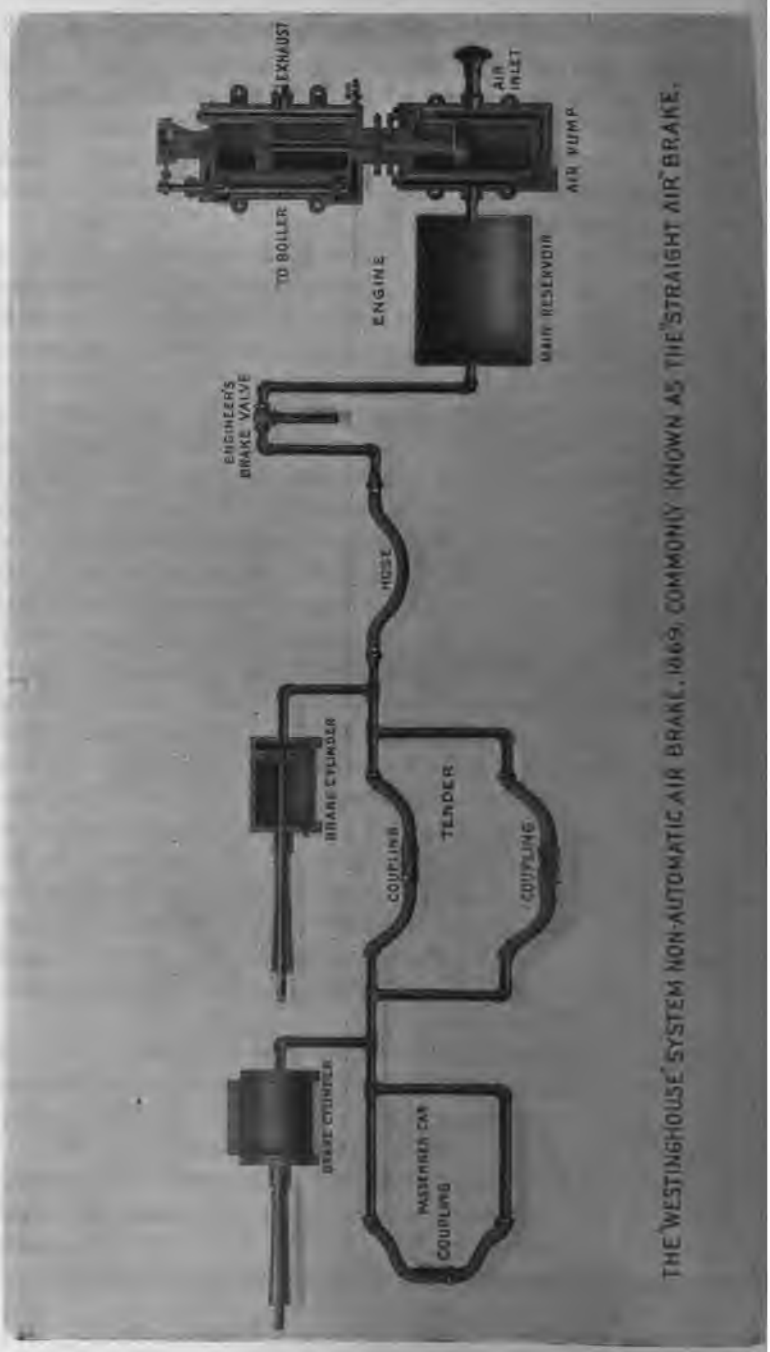
FIRST FORM OF HOSE COUPLING WITH CHECK VALVES AS USED WITH THE STRAIGHT AIR BRAKE OF 1869.

The train was run to Altoona and the air brakes were used exclusively
r controlling the speed of the train on the eastern slope of the
Alleghenies, and special stops were made at the steepest portions of
he line in such an incredibly short distance (as we all thought then)
s to establish firmly in the minds of all present the fact that trains
ould be efficiently and successfully controlled by means of brakes
perated by compressed air.

The next event of importance was the application of the brakes in
November 1869, to a longer train of ten cars upon the Pennsylvania
ailroad, which was taken to Philadelphia for the purpose of demon-
rating to the directors of that railway the success of the apparatus.
may say at this point that the Pennsylvania Railroad had been
sing for some years a chain brake similar to the one applied by
Mr. Ambler, but had found that its use was limited to short trains
nd that it was not a satisfactory contrivance for the purpose intended.
here were invited to witness these trials in Philadelphia a large
umber of railway people and the papers gave extended notices
the tests made, which brought to the train on the next day
Mr. George L. Dunlop, the General Superintendent of the Chicago
North Western Railway, who was desirous of having the whole
pparatus fully explained to him. The result of his inspection of
ne air-brake apparatus was an invitation to make a demonstration
pon his railway in Chicago, and he offered, if the Pennsylvania
ailroad would send a train for the purpose, to invite the leading
ailway people and members of the press of that vicinity. The appa-
atus was then transferred to a train consisting of a new locomotive
nd six new cars, and this train was run to Chicago over the Ft.
Wayne Railroad, and a number of tests were immediately afterwards
nade upon the tracks of the Chicago & North Western Railway,
vidently to the entire satisfaction of those present. From Chicago,
he train proceeded to Indianapolis, where other tests were made,
nd then back to Pittsburgh.

The outcome of these demonstrations was immediate orders for
quipment for the Michigan Central and the Chicago & North Western,
nd shortly after for the Union Pacific Railway in the West and for
he Old Colony and the Boston & Providence roads in the East.

I refer to these details to illustrate the readiness with which railway
fficials took up this invention and the comparative ease with which
he required orders were secured, and because it has been often stated
hat the trials and tribulations in the introduction of the brake were
f the severest nature



THE 'WESTINGHOUSE' SYSTEM NON-AUTOMATIC AIR BRAKE, 1869, COMMONLY KNOWN AS THE 'STRAIGHT AIR' BRAKE.

Works were built in Pittsburgh for the manufacture of the apparatus and were fitted with the best tools obtainable. Standards were adopted and adhered to in the parts of the apparatus which required uniformity in construction in order to insure interchange of the rolling stock so fitted upon various roads. I think I am safe in saying that the course pursued in the manufacture and introduction of the brake had a more important bearing than anything else in deciding the Railway Master Mechanics and Master Car Builders a few years later to take up the question of the standardization of various parts of cars in order that repairs could be more conveniently made.

It soon developed that it took considerable time to apply the brakes with full force and a longer time to release them, and that in the event of a break-in-two of a train (a frequent occurrence in those days) the rear section would be uncontrolled, and when this occurred upon an ascending gradient, the rear detached section might run away with disastrous results. To overcome this difficulty a new development was necessary, the outcome of which was what has since been known as the automatic air brake.

In the automatic air brake equipment there were the same air-pump, reservoir, train pipe and brake cylinder, but in addition to these there were two important features added to the tender and each car equipment: the first, an auxiliary reservoir, and the second, a triple valve or device interposed between the brake pipe, brake cylinder and auxiliary reservoir. This triple valve was so constructed that when air was admitted to the train pipe, an opening was established between the train pipe and the auxiliary reservoir whereby the train pipe and the reservoir were filled with air under pressure. The valve also opened a passage from the brake cylinder to the atmosphere. This was the normal condition of the apparatus when the brakes were off. To apply the brakes, the engineer discharged a portion of the air from the train pipe, whereupon the triple valve closed the connection between the brake pipe and the reservoir and between the brake cylinder and the atmosphere and then opened a passage from the auxiliary reservoir to the brake cylinder, the piston of which was moved outwardly by the air from the auxiliary reservoir so as to apply the brakes. The restoration of the pressure within the brake pipe released the brakes and recharged the reservoir. This development occurred during 1872 and 1873.

The automatic brake was at that time supposed to be instantaneous in its action in applying the brakes, and almost instantaneous in releasing them. In the event of the escape of air from the train pipe

by its rupture or by the separation of the train, the air stored in the auxiliary reservoirs instantly and automatically applied the brakes to all parts of the train and they could be released only by repairing the damage and restoring the pressure, or by means of special release valves operated by the train men.

The automatic brake having proved itself vastly superior to the plain or straight air brake first described, it soon became a standard but during the transition period an automatic brake was easily converted into a plain brake by a manually operated special valve arranged in the casing of the triple valve.

The gradual increase in the length of freight trains and the numerous accidents due to lack of brake control early suggested that automatic air brakes should be made a part of the equipment of all freight trains and to determine the practicability of the automatic brake for this purpose a train of fifty cars was fitted in the early '80s and taken over the Alleghenies on the Pennsylvania Railroad, and the tests made demonstrated that such a train could be controlled on the heaviest gradients by this means.

In 1885 the Master Car Builders appointed a committee to report upon the feasibility of the application of brakes to freight trains, and this committee inaugurated what are now known as the Burlington (Ia.) brake trials made in 1886 and 1887. There were presented two trains fitted with air brakes, one fitted with a vacuum brake and one with the brake operated by means of attachments to the drawbars similar to the conception first referred to. Each of these trains had fifty cars. These tests proved the inadequacy of the type of automatic air brake then presented by the Westinghouse Air Brake Company, as well as the inadequacy of all the other brakes then tested.

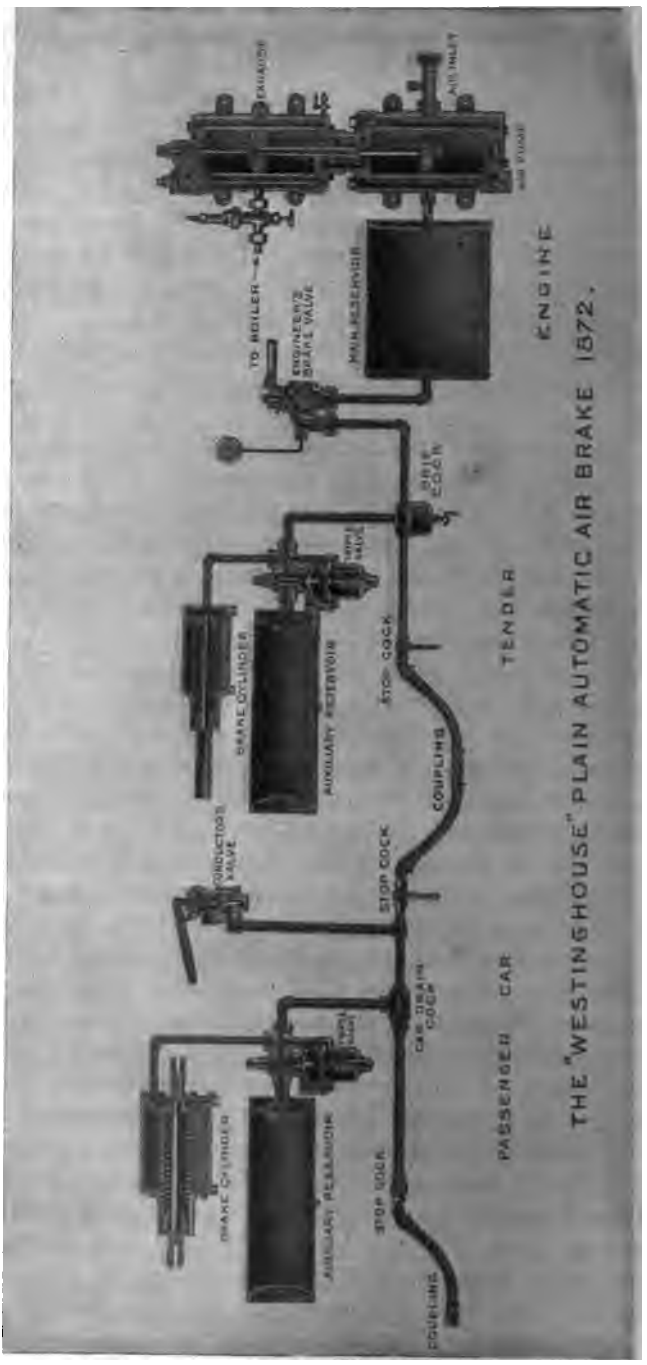
It becoming apparent that the lack of success at Burlington was due to the comparatively slow application of the brakes upon the rear portion of the train, the effect of which was to cause most serious shocks almost like collisions, a new development was imperatively needed in order to insure the successful handling of freight trains of fifty cars.

As a part of the automatic air-brake passenger equipment, I had developed in the '70s a system of train signaling involving the use of a second train pipe, which is now in general use upon all of the railways. This signaling apparatus had a sensitive valve device connected to a small reservoir upon the locomotive and these were so arranged that when compressed air was admitted through a small opening into the signaling pipe, both the pipe and reservoir were

charged to a low pressure (at the present time to 45 lb.). By opening a valve at any point in the train to permit a small quantity of air to escape from the signal pipe, the delicate valve referred to was caused to move so as to admit air from its auxiliary reservoir to blow a whistle located in the cab of the locomotive. It was found upon experimentation that when the valve in any car remote from the engine was quickly opened and closed as many as five times the whistle would be blown an equal number of times, the first time being after the last escape of air; that is to say, there were set in motion five distinct waves of air each capable of doing work.

During these developments it was found that the waves of air within the brake pipe traveled as rapidly as sound, i.e., about 1100 feet a second.

Being fully impressed with the idea that if the wave of air which was utilized for signaling could be made to operate the triple valves upon the cars, there would then be an almost instantaneous application of the brakes upon the front, rear and other portions of the train, this idea, with hard work and a large number of experiments, shortly produced what is now known as the quick-action automatic brake. The Westinghouse train was left at Burlington in order that the new triple valves with the quick action attachment could be applied and further experiments made. The valves as developed for this emergency proved to be successful and the tests made with this train after their application were eminently satisfactory to the railway officials. It was thereupon arranged to take this train to Minneapolis and St. Paul, Milwaukee, Chicago, St. Louis, Cincinnati, New York, Albany, through to Boston and New England, to Washington, and then to Pittsburgh, innumerable demonstrations being made during this journey of some thousands of miles. This train, drawn by two locomotives, was frequently run at speeds above fifty miles an hour and the tests were witnessed by all of the prominent railroad people of the country. So great was the demand for good brakes on freight trains that considerable difficulty was at first experienced in promptly filling the orders of railway companies. Nevertheless, the wide publicity given to these tests, coupled with a public demand for the adoption of means to prevent accidents, brought about the enactment of a law by the Congress obliging the railways to apply brakes and also automatic couplers to all freight trains in the United States within a time named in the Act, which time was subsequently extended because it was physically impossible for the railway companies to make the introduction within the time first prescribed.



THE "WESTINGHOUSE" PLAIN AUTOMATIC AIR BRAKE 1872.

he quick-action automatic brake was operated like the first automatic rake for ordinary train movements; the quick action resulted only 'hen it was necessary to apply the brakes for an emergency.

No sooner had the quick-action automatic brake been developed o operate successfully on trains of fifty cars than new conditions /ere presented. Steel freight cars carrying enormous loads had in he meantime been developed and freight locomotives had been ıcreased in capacity, so that trains were often composed of 70 to) cars and more recently some trains have had as high as 100 cars. his possibility had, however, been foreseen and experiments were ›nstantly being carried on so to improve the apparatus, that it ›uld be used to control trains of any practical length; and these ;periments also had in view the more nearly instantaneous action ' the brakes for ordinary service purposes than was possible with ıe automatic brake or with the quick action brake. The result as a most important development.

The present improved triple valve has the emergency feature, but also has what is known as the quick-service application feature; ıat is, for ordinary purposes the air is admitted to all of the brake /linders so quickly that the longest freight train can be handled ith almost the precision obtainable in the control of passenger trains ' from six to twelve cars.

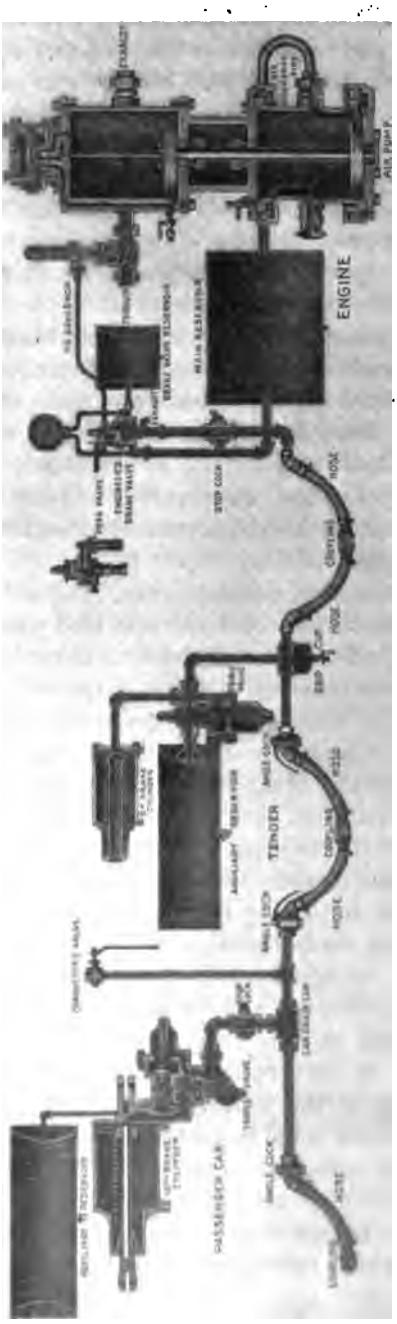
In the matter of the development of the brakes for operation upon ıssenger trains, nothing that skill and perseverance could suggest ıs been omitted in securing the highest degree of perfection. The quirements during the past few years, by reason of the greater ›ight of cars and locomotives and of the higher speeds at which they e run, have necessitated the redesigning of all of the passenger train ake apparatus, including the method of attaching the brake shoes the cars and the levers and connections for bringing these shoes bear with the required pressure upon the wheels. For the purpose insuring the highest efficiency, every wheel of a passenger train, ›luding those under the locomotive, is now acted upon, whereas rmerly many of the master mechanics and engineers were appre- nsive that it would not be possible to make use of all of the wheels a locomotive for braking purposes.

During the past twelve months, most elaborate tests of the latest rm of apparatus for passenger service have been carried out under e direction of officials of several railways and of the Westinghouse r Brake Company, in order to prove the operativeness of the new nstructions and their capability to insure the highest degree of ficiency.

From the very beginning of its operations, the Brake Company has maintained a strong staff of experienced engineers, some of whom are located in each of the large railway centers and whose services are always at the command of the railways. It is the duty of one or more of these trained men to proceed to the scene of any accident that may have occurred in order to ascertain the cause, to report thereon and to render such aid and coöperation to the railway officials as will tend to avoid a like accident if in any manner the brake can contribute to that end.

The Air Brake Company has always had in its works, for experimental purposes, sets of brake cylinders, pipes and couplings, representing the apparatus upon trains of various lengths, so that tests and demonstrations could be readily made for all sorts of purposes, including the educating or informing of railway officials who came to seek information. To spread this information more effectively, the company about fifteen years ago constructed and equipped a special instruction car in which were arranged 50 sets of brake cylinders and pipes equivalent to like apparatus upon a freight train. This car was provided with a boiler to drive the air pump for the production of the air under pressure needed to operate the brakes. Operative models of all parts of the apparatus were shown in section so that their construction and operation could be more quickly comprehended. This car, in charge of experienced instructors, was moved from place to place, and engineers, firemen, conductors, and other train employees in general visited it to familiarize themselves not only with the operation of the brake but with its construction, and in this manner there has been developed throughout the country a knowledge of the air-brake art which has proved of inestimable value to the railway corporations and their patrons. The records of the Westinghouse Air Brake Company show that to December 1, 1910, their instruction car had travelled over 113,000 miles. Numerous railways have also provided their own instruction cars, so that it may be safely said that every railway employee having anything to do with the operation of trains, freight or passenger, has been required to familiarize himself with the working of the brakes and so to study the subject that he could pass an examination, 280,258 employees having so far been examined by representatives of the Westinghouse Air Brake Company, and in numerous cases these men have been required to show sufficient knowledge of the brake to entitle them to receive certificates of their proficiency.

The importance of the maintenance of the brake to railways has



THE "WESTINGHOUSE" SYSTEM QUICK ACTION AUTOMATIC BRAKE 1887.

not been overlooked by railway officials. They have appointed su intendents of brakes and numerous inspectors, and there is an a ciation of air-brake officials, organized in 1893 and now having members who meet annually in convention to discuss thoro the questions which are constantly arising, so that today there an organization of which scarcely any of the public has ever he an organization which is constantly devoting skill and ener the care of apparatus which above everything else in connectio railways contributes to the safe transportation of passenger freight.

I have often been asked how many lives have been saved b use of the air brake and I have as often said it might well be s many thousand, but that it was impossible to make even an ap mate estimate. At a banquet given in Washington to the me of the International Railway Congress in May 1905, a diplom speaking on the subject of the importance of railway brakes, s felt safe in saying the air brake had saved more lives than any g had ever lost in a great battle.

I have spoken of four chief developments. It has been nec in order to avoid disastrous consequences, that each develc should be of such a kind that cars fitted with newer apparatu operate with little inconvenience with cars fitted with earlier a tus. As it stands today scarcely any of the old type of brake a first type of automatic brake are in use, but should a car fitte the first form of automatic brake be found and put into a trai the more modern apparatus, such older apparatus would be to operate fairly well with the more perfect form. The prevaili in the development and introduction of the brake has therefo an adherence to such uniformity of apparatus that the inter of traffic over various roads could go on uninterruptedly.

There is probably no apparatus in use today which has r such thoughtful consideration and been the object of such every one of its details as what is now popularly known as brake, and which is in universal use in the United States many other countries of the world.

In my estimation, there could be no better illustration of th of the maintenance of standards than has been given by the facture and introduction of air brakes upon railways, for such standards, train brakes would not have come into gen with consequences which railway officials and the public c appreciate.

My story would be incomplete without a reference to the splendid assistance which the railways of this and many other countries have rendered. They have been lavish in providing those facilities for making the thousands of tests which were necessary to progress in the developments I have recited; to the Pennsylvania Railroad especially, upon which the most important experiments were first made, the other railways of the country, as well as the traveling public, owe a debt of gratitude. When a railway (as did the Southern Pacific two years ago) provides a new train of 100 steel cars to be fitted with the newer form of automatic brake, in order to carry on, with a staff of skilled men under the direction of the chief officers of the company, a series of experiments upon its heaviest gradients, requiring several weeks, for the purpose of securing greater safety and an increased carrying capacity per train, with the consequent lessening of the cost of transportation, it is just that the managers of such a corporation should receive credit for their farsighted policy. To name the railways and merely to state chronologically the tests of brakes which have been made during forty years would require several volumes.

It only remains for me to say that I am extremely gratified by the patience and attention with which you have listened to the reading of this address, and I am amply repaid if what I have said has been illustrative and interesting to you.

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My story would be incomplete without a reference to the splendid assistance which the railways of this and many other countries have rendered. They have been lavish in providing those facilities for making the thousands of tests which were necessary to progress in the developments I have recited; to the Pennsylvania Railroad especially, upon which the most important experiments were first made, the other railways of the country, as well as the traveling public, owe a debt of gratitude. When a railway (as did the Southern Pacific two years ago) provides a new train of 100 steel cars to be fitted with the newer form of automatic brake, in order to carry on, with a staff of skilled men under the direction of the chief officers of the company, a series of experiments upon its heaviest gradients, requiring several weeks, for the purpose of securing greater safety and an increased carrying capacity per train, with the consequent lessening of the cost of transportation, it is just that the managers of such a corporation should receive credit for their farsighted policy. To name the railways and merely to state chronologically the tests of brakes which have been made during forty years would require several volumes.

It only remains for me to say that I am extremely gratified by the patience and attention with which you have listened to the reading of this address, and I am amply repaid if what I have said has been illustrative and interesting to you.

not been overlooked by railway officials. They have appointed su intendents of brakes and numerous inspectors, and there is an ciation of air-brake officials, organized in 1893 and now having members who meet annually in convention to discuss thoro the questions which are constantly arising, so that today there an organization of which scarcely any of the public has ever he an organization which is constantly devoting skill and ene the care of apparatus which above everything else in connectio railways contributes to the safe transportation of passenge freight.

I have often been asked how many lives have been saved l use of the air brake and I have as often said it might well be many thousand, but that it was impossible to make even an a mate estimate. At a banquet given in Washington to the m of the International Railway Congress in May 1905, a diplo speaking on the subject of the importance of railway brakes, felt safe in saying the air brake had saved more lives than any had ever lost in a great battle.

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No. 1296

PICAL DISCUSSION ON THE PROBLEM OF SMOKE ABATEMENT

INTRODUCTORY DISCUSSION BY D. T. RANDALL

ıe abatement of smoke from bituminous coal is an engineering ·lem. In choosing a coal for use in a given plant, the following ts should be considered:

a The amount and character of the volatile matter
b The amount of ash and its tendency to clinker
c Moisture
d Coking and caking qualities
e Size
f Amount to be burned in a given furnace
g The kind of furnace, hand-fired or automatic
h The draft available and its regulation
i The character of the load, steady or variable
j The ability of the firemen

ost of our boiler plants were originally built to burn anthracite , not many being properly equipped to burn the higher volatile minous coals. The burning of bituminous coal is more compli- d for the reason that on charging the coal upon the fuel bed, the tile gases begin to distill off as soon as the coal is heated to the ired temperature. These gases are similar in character to un- fied illuminating gas and contain tar and heavy hydro-carbons and produce smoke unless burned under very favorable conditions. r could be admitted in sufficient quantities and in such manner) mix thoroughly with these gases as they are being distilled from coal, they could be completely burned without smoke, provided temperature of the furnace was sufficient to ignite them. The l carbon, or portion of the coal corresponding to coke, remains on grate and is burned under the conditions described for coke or other s containing a low percentage of volatile matter.

esented at the Boston meeting, November 1910, of THE AMERICAN SOCIETY IECHANICAL ENGINEERS.

It appears from the experiments of Dr. Horace C. Porter, of the Bureau of Mines, that coals vary considerably in the character of their volatile matter, and that their percentage as determined by proximate analysis is not necessarily a correct measure of the difficulty which may be expected in preventing smoke. The volatile matter is composed in part of inert matter such as carbon dioxide and other combinations which do not burn, and the real volatile combustible matter may be much less than appears from the ordinary coal analysis. When coals of the same general character are considered, however, the volatile matter is a very fair measure of the difficulty which may be experienced in burning them without smoke. The difference between a coal containing 16 per cent volatile matter and another one containing 21 or 22 per cent is usually noticeable when a hand-fired furnace is used. A coal containing more than 25 per cent volatile matter is difficult to burn without smoke.

If the coal contains large quantities of ash the fires must be cleaned more frequently, and in addition it is difficult to secure an even distribution of air through the bed of fuel and ash. If the ash has a low fusing point and melts and sticks to the grate, air will be shut out over portions of the grate and the difficulty of preventing smoke will increase.

An increase in the moisture in the coal usually increases the difficulty of burning it without smoke. If a coal cokes in the fire and if the draft is such as to require the frequent breaking up of the fuel bed, the coal may give off more smoke at such times than when it is fired.

The size of the coal is of considerable importance for the reason that coals which are coarse must be carried at greater depth on the grates in order to prevent an excess of air, and the finer coals must be fired very carefully in order that they may not clog the air openings through the fuel bed and thus prevent a sufficient amount of air reaching the gases from the coal. Generally speaking, coal which is fine in size must be fired in smaller quantities than coals which are in the form of lumps and records of analyses show a wide variation in coals sold for power plant purposes, the volatile matter ranging from 16 to 35 per cent, the ash from 5½ to 14 per cent, and the heating value from 13,000 to 14,600 B.t.u.

DESIGN OF FURNACES

It is evident that the design of a furnace for bituminous coal must be different from one for coke or anthracite coal. The most successful

designs provide for the admission of air to mingle with the liberated gases and also arrange some device which causes them to mix or burn before they leave the furnace, a time which probably does not exceed a second. Walls or arches are often provided which cause the gases to whirl and mix, and long or high combustion chambers are provided to allow time for the combustion to take place.

If it is found that an equipment is not satisfactory even when the most successful methods of firing are adopted, it will then in most cases be good business policy to invest in an improved type which will give practically complete combustion. There are many cases where the equipment is old and it would not be advisable to install new and expensive furnaces under an old boiler, or the power plant may be in a rented building, or for other reasons it may not be feasible to improve the furnaces. In such cases the solution must lie along the lines of choosing a coal which is best suited to the furnace which is installed. With such furnaces by mixing bituminous coal with an equal weight of anthracite screenings, quite satisfactory results may be obtained and without much difficulty from smoke. To burn such a mixture usually requires a little stronger draft than for bituminous coal alone.

In designing a combustion chamber, it is not necessarily a solution of the problem to provide a chamber of large capacity, unless it is of such shape that the gases can be made to pass at a fairly uniform velocity over its entire cross section. A study of a great many plants seems to indicate that the distance through which the gases travel before they reach the heating surface is of more importance than the area of the passage through which they travel, for the reason that they have a tendency to travel in lines the shortest distance from the grate to the heating surface and thus to make a considerable portion of the combustion chambers merely dead spaces and inactive so far as combustion is concerned. In this connection it has been noted that the common, horizontal return tubular boiler has given very good results in comparison with other types of boilers, evidently because of the length of the travel of gases. Whenever a device is provided which tends to give a more intimate mixture of the air with the gases, it is possible to shorten the combustion chamber accordingly.

For each kind of coal and each furnace, there is apparently a range of capacity through which it is possible to operate without a serious production of smoke. At higher rates the efficiency decreases and black smoke is produced owing to a lack of furnace capacity to supply air and mix it with the gases.

The operation of firing a furnace by hand is of necessity an inter-

mittent one. Relatively large quantities of fuel must be placed on the fuel bed at one time. This fuel tends to retard the flow of air and at the same time the heat in the furnace tends to drive off the gases rapidly. Usually enough air cannot be supplied at this time and there is smoke for a minute or two after each firing, even when the stack is clear during the remainder of the time.

Hand-fired furnaces depending upon brick-work baffles, arches and piers are better than plain furnaces, and they generally decrease the smoke after the brick work is heated. Their capacity to absorb heat tends to counterbalance the gain from better combustion if a large amount of brick work is used and if the period of operation is short. A brick arch over the entire grate surface increases the rate of combustion for any given draft because it reflects heat back onto the fuel bed and assists in driving off the moisture and the volatile matter from the coal. This action may cause more volatile matter to escape than can be burned in the combustion chamber provided. In many cases more successful results in preventing smoke are obtained by omitting the arch above the grate and providing arches, piers, checkerwork, or similar construction at the bridge wall and a short distance behind it. Provisions for admitting extra air for a short period after each firing will often reduce the smoke to one-half the amount produced when only the regular supply is furnished through the grates and fuel bed. In general, furnaces based on such designs may be operated by skilled firemen with certain coals with good economy and with smoke only at short intervals after each firing or cleaning provided the rate of combustion is low.

Hand-fired furnaces properly equipped with steam jets and air admission may be operated with most coals so as to give but little black smoke except when cleaning the fires. The jet must be located so as to direct the current in the required direction to secure a rapid mixture of the gases from the coal with the air in the furnace. This often requires some experimenting. Steam jets require a large amount of steam to secure satisfactory results, but their use improves the combustion and if the methods of firing are improved when the apparatus is installed, the loss due to the use of steam may be fully or partially offset by the resulting economy. In connection with large combustion chambers or well-designed brick furnaces, fewer jets may be used or the pressure may be reduced to save steam.

In furnaces having the heating surface directly above the grate it is necessary to accomplish the admission of air by steam jets, unless sufficient air can be admitted uniformly through the grates.

A study of tests conducted at the Government fuel testing plant shows that with hand-fired furnaces the best results were obtained when the firing was done most frequently and with the smallest charges of coal. In general, coals which smoke badly give efficiencies from 3 to 6 per cent lower than coals which burn with but little smoke; also when the air supply is reduced and the furnace temperatures increased there is an increase in CO_2 and in CO which is always accompanied by smoke. In many cases there may be smoke and a considerable unaccounted-for loss when there is but little or no CO determined by the Orsat.

DESIGN OF STOKERS

These problems have led a number of inventors to design automatic stokers. With these the coal is fed in small quantities continuously in such a way as to be subjected to the heat gradually and at a comparatively low temperature and the gases are driven off mixed with air and completely burned in a combustion chamber before they reach the cooling surface of the boiler tubes. Many of these have been improved until they may be depended upon under normal conditions to burn almost any kind of bituminous coal successfully, when they are properly installed and operated. As a rule this installation included special settings and combustion chambers, depending upon the kind of boiler and of fuel to be used.

The chain grate stoker as ordinarily designed is very successful in burning high volatile and high ash coals. Under proper operation it is capable of burning such coals at high rates of combustion without smoke, and in some well-designed plants it is difficult to make these furnaces smoke even when they are improperly operated. These stokers are not adapted to burning low volatile coking coals.

Several makes of stokers on the market are designed to feed the coal from hoppers onto inclined grates, kept in motion by a driving mechanism. Some are so designed as to grind through a large portion of the ash which accumulates at the bottom of the grate. Whether this type of stoker is successful or not depends not only on its durability and resistance to the action of the heat, but also on its ability to feed the coal uniformly, heat it gradually and introduce a supply of air which will mix with and burn the gas before it has traveled far from the point at which it is liberated. Many stokers of this type are so installed and operated as to give good efficiency and smokeless combustion, but there are many others which smoke badly.

Only within the last few years have the manufacturers of such equipment given serious consideration to the smoke problem and recognized that the stokers must be set in furnaces especially designed with due regard to the kind of coal, boiler and service for which they are intended. It is a mistake to install these or any other stokers in the belief that they do not require as much skill to handle as a hand-fired plant, provided good results are to be secured. They may require even greater skill. There are two or three makes of underfeed stokers on the market. If they are so designed as to be automatic in regard to the supply of coal and air, they may be operated with very good efficiency, and when reasonable care is given to the operation, they will burn the high volatile coals with but little, if any, smoke except at the times when they are being cleaned. Owing to the fact that the air is supplied to these stokers under pressure and forced through the fuel bed, it is possible to secure an intimate mixture of the air and gases and to burn within a short distance from the fuel bed. For this reason the combustion space required is usually less than with other types of stokers. In some cases the mistake has been made of installing a stoker too small for the purpose, and the results have been unsatisfactory as the capacity of the boiler could be obtained only with difficulty, the combustion was poor and oftentimes the stack was smoky.

FURNACE EQUIPMENT

No other equipment in connection with a power house requires to secure satisfactory results the same degree of care and experience in its selection as do the furnace equipment, and the boiler and furnace setting. The problem of smoke abatement in power plants is by no means solved when competitive bids are secured from stoker manufacturers and an equipment contracted for, even though smokeless operation is guaranteed by the maker. The draft and its method of regulation must always be taken into consideration both in hand-fired plants and automatic stoker-fired plants. The best results are usually obtained when the draft is low, because it is less difficult to maintain an even fuel bed and there is less leakage of air through holes in the setting. A great many chimneys are smoky because the draft is insufficient to supply air in the correct proportion at critical periods of operation.

Damper regulators are frequently the cause of smoke, due to the fact that they are not properly adjusted, and it often happens that firemen charge large quantities of coal into the furnace with dampers closed and no air admitted to burn these gases.

Difficulty is also experienced in preventing smoke at times when the load changes rapidly, or when the boilers are heavily overloaded. Oftentimes the furnaces will smoke when boilers are cut out and banked, and they are equally liable to smoke when they are being brought from a banked condition into service.

It is very difficult to start a fresh fire with bituminous coal under a boiler without producing smoke. In cities where there is a smoke ordinance it is quite often the practice to start fresh fires before the smoke inspector is on duty. This problem is being met at the present time in some boiler plants, in foundry cupolas and other industrial furnaces, by using a bed of coke, ignited by means of a gas or oil flame from a portable burner installed for the purpose. Such a procedure will build up a fuel bed and bring the furnace walls up to a temperature so that fresh coal may be fired without particular difficulty. This plan is of course more expensive and more troublesome than to start the fire with some kindling and bituminous coal as has been the custom for a long time.

Furnaces may be grouped as follows:

a With iron-enclosed combustion chamber and short gas travel, such as house-heating boilers, internal fire-box boilers, and vertical boilers not provided with extension furnaces.

b With brick side walls, small combustion chambers and short gas travel, such as water-tube boilers with grates directly below the heating surface.

c With iron surfaces of boilers forming roof of combustion chamber, and long gas travel, such as horizontal return tubular, Heine type, etc.

d With brick-enclosed combustion chamber and long gas travel, with special arches, piers, etc., to aid in mixing air and gases.

e Any one of the above equipped with automatic steam jets and air admission.

f Any one of the above equipped with automatic stokers.

DESCRIPTION OF TESTS

To illustrate the variations in conditions under which coal is being burned, tests were made, and are herewith tabulated in Tables 1 to 7.

The observations in Table 1 were made at an electric light plant on B. & W. boilers, rated at 350 h.p. each. These boilers were set at a height to give about 42 in. between the grate and tubes of the boiler.

TABLE 1 TEST ON B. & W. BOILERS

Time	Draft Back of Boiler	Thickness of Fire	Gas Analyses Per Cent by Volume			Remarks
			CO_2	O_2	CO	
4.03	....	18	....	...	...	Fired 14 shovels coal
4.07	0.10	18	13.6	1.5	2.3	4 min. after firing
4.20	....	18	....	...	...	Fired 15 shovels
4.25	0.11	17	12.5	1.1	3.5	5 min. after firing
4.37	....	18	....	...	...	Fired 14 shovels
4.42	....	18	....	...	...	Raked fire
4.45	0.21	18	13.7	1.0	6.7	3 min. after raking
5.05	....	18	....	...	...	Fired 15 shovels
5.15	0.25	18	18.2	0.6	1.0	10 min. after firing
5.33	....	18	....	...	...	Fired 16 shovels
5.35	0.20	18	15.3	1.0	3.6	2 min. after firing
5.55	....	....	....	...	...	Fired 17 shovels
5.58	0.08	19	12.0	0.3	4.7	3 min. after firing

TABLE 1a SPECIAL DRAFT READINGS TO SHOW ACTION OF DAMPER REGULATOR

Time	Draft at Outlet from Boiler	Remarks
p.m.		
6.25	0.06	Damper closed
6.26	0.35	Damper half closed
6.27	0.07	Damper closed
6.30	0.42	Damper open
6.32	0.46	Damper open

It will be seen from the analyses that when several shovelfuls of coal were fired at one time, large amounts of carbon monoxid and unburned gas escaped from the furnace and that there was also a considerable loss after long intervals if the damper was nearly closed. The stack smoked almost continuously during this period and the smoke was more than 60 per cent black for periods of four or five minutes after each firing. These readings in this table indicate the frequency of changes in the draft due to the action of the damper regulator. Such changes are unfavorable to good combustion. A damper regulator in perfect working order should not permit of such fluctuations in draft. The analysis of coal burned at this plant was as follows:

Moisture	2.79
Volatile	16.30
Fixed carbon	73.99
Ash	6.92
	100.00
Sulphur	0.61
B.t.u.	14,207

These results indicate that the conditions under which the coal was burned were very unfavorable, that the fire was too thick, that too much coal was fired at one time, and that the draft was not properly regulated. The combustion chamber is small and the gases pass directly from the fuel bed to the boiler tubes with but little opportunity to mix the gases from different parts of the grate. With such a furnace it is possible to have too little air on one side and too much air on another. Frequently there will be incomplete combustion and an excess of air at the same time.

TABLE 2 TESTS ON A CLIMAX BOILER

Time From	Time To	Draft Over In. of Water	Steam Pressure	Flue Temp. Deg. Fahr.	Gas Analyses Per Cent by Volume CO_2	O	CO	N	Air Excess Per Cent
a.m.	a.m.								
9.00	9.30	0.11	99	565	12.6	6.2	0.0	81.2	41
9.30	10.00	0.13	98	565	13.8	4.6	0.1	81.5	27
10.00	10.30	0.12	101	595	14.6	4.0	0.2	81.2	23
10.30	11.00	0.11	99	575	14.9	3.9	0.1	81.1	23
11.00	11.30	0.17	97	545	12.6	6.6	0.0	80.8	45
11.30	11.58	0.11	97*	540	13.4	5.5	0.0	81.1	35
p.m.	p.m.								
1.30	2.00	0.17	98	595	12.5	6.3	0.1	81.1	42
2.00	2.30	0.15	100	535	13.7	5.5	0.0	80.8	35
2.30	3.00	0.21	97	535	13.4	5.7	0.0	80.9	37
3.00	3.30	0.18	97	565	11.5	8.0	0.0	80.5	61
3.30	4.00	0.19	98	575	12.9	6.5	0.0	80.6	44
4.00	4.30	0.21	97	570	14.3	4.8	0.1	80.8	29
4.30	5.00	0.17	98	560	14.2	4.9	0.0	80.9	30
5.00	5.30	0.16	99	545	14.5	4.3	0.0	81.2	25
5.30	5.55	0.28	..*	545	14.4	4.7	0.3	80.6	29
Average.....		0.16	98	560	13.6	5.4	0.1	80.9	35

*Hand damper dropped.

The results in Table 2 were obtained on a Climax boiler, rated at 800 h.p. This boiler was provided with a plain grate, having 125 sq. ft. of surface. The distance between the grate and the boiler tubes was $3\frac{1}{2}$ ft., the tubes being directly over the fire. The rate of

combustion was low, being approximately 12 lb. of dry coal per sq. ft. of grate. The coal used was of the character shown by the following analysis:

Moisture	2.12
Volatile	16.38
Fixed carbon	75.47
Ash	6.03
	100.00
Sulphur	1.03
B.t.u.	14,431

This furnace is open to the same criticism as that in Table 1, but the results are good because of exceptionally good firing.

TABLE 3 RECORD ON HORIZONTAL RETURN TUBULAR BOILER

Time	Min. after Firing	Coal Fired Shovels	Thickness, In.	Draft Furnace	Draft Outlet	Gas Analyses Per Cent by Volume			Remarks
						CO_2	O_2	CO	
10.40	..	8	10	....	....	....	....	....	No smoke
10.45	5	..	..	0.25	0.47	11.6	8.2	0.0	.....
10.51	..	7	10	....	....	....	....	....	No smoke
11.00	9	..	..	0.26	0.50	12.8	6.4	0.0	.....
11.05	..	9	10	....	....	....	....	....	No smoke
11.13	..	..	..	....	....	....	....	....	Raked fire Trace smoke
11.15	10	..	11	0.25	0.48	13.5	5.8	0.8	.....
11.17	..	8	10	....	....	....	....	....	10% smoke ½ minute
11.23	..	8	11	....	....	....	....	....	10% smoke ½ minute
11.30	7	..	..	0.24	0.48	13.2	6.6	0.0	.....

Note.—When fire is loosened by bar, smoke as high as 60 per cent is given off for about ½ minute and an average of about 20 per cent for two minutes after.

There were four furnace doors equally spaced around the circumference of the furnace. Coal was fired in quantities of about five shovelfuls at a time and at regular intervals. At times just after firing there would be a very thin smoke at the top of the stack. In many cases there was no smoke. On two or three occasions the smoke reached a density of 40 per cent for a period of about one-half minute after firing. This plant was practically smokeless except at times when the fires were banked or when they were broken up after having been banked and when cleaning the fires. It was only for a very short period of time that the smoke was darker than 60 per cent black. This plant smoked about 40 per cent black for one-half minute after firing

when the coal was very wet. Full capacity could not be carried without smoking seriously.

The behavior of the same coal in another plant under a return tubular boiler is shown in Table 3. The boiler was provided with a rocking grate having an area of 36 sq. ft. The fireman was not a highly trained one, but the fires were maintained in good condition and there was practically no smoke during the periods of regular operation. The load was nearly constant. This furnace has a long combustion chamber and is not nearly so sensitive to changes in the thickness of the fire or the amount of coal charged at one time as the furnaces described under Tables 1 and 2.

The observations in Table 4 were taken on a 225-h.p. vertical fire-tube boiler of the Manning type, having a grate surface of 41½ sq. ft. and provided with two firing doors and eight steam jets. The dis-

TABLE 4 GAS SAMPLES TAKEN AT POINT WHERE FLUE GASES LEAVE BOILER ROOM

Time*	CO_2	O_2	CO	N_2	Draft, In. of Water		Flue Temp.
					Over Fire	In Flue	
1.00	12.0	8.0	0	80.0	0.30	0.40	470
1.20	11.0	7.9	0	81.1	0.35	0.35	480
1.40	11.8	7.7	0	80.5	0.30	0.30	470
2.00	10.2	9.3	0	80.5	0.30	0.40	490
2.20	11.2	8.3	0	80.5	0.30	0.35	490
... †	12.6	6.2	0.8	80.4	....	....	...
....	12.6	6.6	0.6	80.2	....	....	...
....	11.9	7.4	0.9	79.8	0.25	0.30	490
....	13.5	5.4	0.6	80.5	....	....	...

* Steam jets in operation. † Steam jet off.

tance from the grates to the heating surface is 6 ft. This furnace is similar to those in Tables 1 and 2 and can not be operated at full capacity without smoke unless steam jets are used. The coal burned showed the following composition:

Moisture	1.87
Volatile	18.18
Fixed carbon	73.55
Ash	6.40
	100.00
Sulphur	0.63
B.t.u.	14,538

Each steam jet draws in a quantity of air through a pipe which surrounds it. Provision is made to regulate the amount of air supplied with the steam. These steam jets are located about 3½ ft. above the grate surface. The thickness of fire is maintained at about 12 in. and the fuel bed is kept as level as possible. Coal is charged in quantities of 8 or 9 shovelfuls at a time through one door of the furnace. At intervals of about 8 or 10 minutes, depending upon the load, the other door is charged with a similar quantity of coal. The rate of combustion is about 20 lb. of coal per sq. ft. of grate.

TABLE 5 TESTS ON PLANT HAVING HORIZONTAL RETURN TUBULAR AND STIRLING BOILERS

Time	After Firing	Damper had been Closed or Open	Position of Damper	Draft, In. of Water: Over Fire	Draft, In. of Water: In Flue	Flue Temp. Deg. Fahr.	Gas Analyses Per Cent by Volume: CO_2	Gas Analyses Per Cent by Volume: O	Gas Analyses Per Cent by Volume: CO	Gas Analyses Per Cent by Volume: N	Air Entering Per Cent
STIRLING BOILER											
10.40	4	1	Closed	0.04	0.05	480	12.7	0.9	7.0	79.4	5
10.55	2	9	Open	0.03	0.04	455	13.4	0.5	4.9	81.2	3
11.10	10	24	Open	0.11	0.16	445	7.1	12.1	0.8	80.0	100
1.05	2	5	Closed	0.03	0.04	445	16.2	0.6	0.8	82.4	3
1.20	6	11	Open	0.17	0.26	455	5.5	14.9	0.0	79.6	200
1.35	2	1	Closed	0.03	0.04	420	13.0	1.0	4.6	81.4	5
1.50	8	3	Open	0.09	0.12	420	8.8	9.9	1.9	79.4	10
2.05	5	18	Open	0.08	0.11	410	10.1	8.3	1.4	80.2	65
Average				0.07	0.10	440	10.8	6.0	2.7	80.5	65
HORIZONTAL RETURN TUBULAR											
2.30	5	43	Open	0.16	0.23	455	11.5	8.5	0.0	80.0	65
2.45	0.05	58	Open	0.09	0.13	450	13.4	7.0	0.0	79.6	50
3.00	0.05	73	Open	0.15	0.21	475	13.3	5.5	0.0	81.2	35
3.15*	2	88	Open	0.13	0.19	500	15.0	3.8	0.4	80.8	22
3.30	2	103	Open	0.15	0.22	490	12.6	7.2	0.0	80.2	45
3.45	12	9	Closed	0.14	0.20	450	11.6	8.8	0.0	79.6	75
4.00	7	24	Closed	0.13	0.17	460	12.1	8.0	0.0	79.9	65
Average				0.14	0.19	470	12.8	7.0	0.1	80.1	52

	Stirling	Horizontal Return Tubular
Average thickness of fire, in.	11	9
Average weight of coal fired each time, lb.	65	55
Average interval between firings, min.	9	7
Intervals between firings vary		
from, min.	8	2
to, min.	18	16
Per cent of time damper		
open	60	80
closed	40	20
Lb. of coal burned per sq. ft. of grate surface per hr.	16.3	14.1

*Sliced fire 3.14½

To determine the effect of the steam jets, observations were taken with and without them.

With the steam jets on there was practically no smoke issuing from the top of the stack and it would be classed as a smokeless plant. Without the steam jets, it will be noted that there was considerable unburned gas and there was smoke varying from No. 1 to No. 3, Ringelmann's chart. While this would not be classed as a dense black smoke, and the plant would not be subject to a fine under most city ordinances, it would indicate that a little carelessness on the part of the fireman would without doubt cause dense smoke and subject the plant to fines.

The observations in Table 5 were taken in a boiler plant burning coal which analyzed as follows:

Moisture	3.38
Volatile	20.32
Fixed carbon	66.94
Ash	9.36
	100.00
Sulphur	2.22
B.t.u.	13,528

The plant was equipped with a 150-h.p. horizontal return tubular boiler having 33 sq. ft. of grate area, and a Stirling boiler rated at 225 h.p., having a grate area of 48 sq. ft. The draft was regulated by means of a damper regulator operating on individual dampers on each of the boilers.

TABLE 6 B. & W. TYPE BOILER HAND-FIRED

Time	Draft		Temperature Flue Gas	Thickness of Fire, In.	Shovels Fired	Min. after Firing	CO_2	O_2	CO
	Furnace	Boiler							
2.20	0.37	0.46	675	5	18	..	..	..	..
2.25	..	.	765	..	..	5	7.5	11.9	0
3.00	0.36	0.47	725	5	16	..	..	..	..
3.04	..	..	745	..	..	4	7.3	12.0	0
3.25	0.37	0.48	680	6	17	..	..	..	..
3.27	.	.	..	..	..	2	8.1	9.6	1.2

Note.—This plant smoked 100 per cent black for about 2 minutes after each firing, and did not clear up for 5 or 6 minutes. Average period between firings about 10 minutes.

During the time the observations were taken on the Stirling boiler the load was light and the damper was closed most of the time. The stack smoked badly during this period. During the period of observations on the horizontal return boiler the greater part of the load was placed on it. A higher rate of combustion was maintained and

boilers. It is demonstrated that plain hand-fired furnaces may under very favorable circumstances be operated without smoke, but that under ordinary conditions they will be inefficient and smoky.

The results in Table 7 are from U. S. Geological Survey Bulletin 373. During the investigations of smokeless plants it was noted that very few plants were being fired by hand without smoke unless steam jets were used for at least a minute or two after each firing. Some plants were doing fairly well without steam jets, but they were in many cases burning large-sized coal and admitting an excess of air, or they were operating at low capacity. Some of the better operated plants were not smokeless but the stacks smoked only for one or two minutes after each firing, beginning with a density of about 60 per cent black and diminishing to about 20 per cent at the end of a half minute. Such plants are not usually subject to fines.

GENERAL DEDUCTIONS

General deductions may be drawn as follows:

a Plain hand-fired boilers may be operated with but little smoke with low volatile coals, or in some cases, with other coals if the rate of combustion is low.

b Hand-fired furnaces with brick arches, etc., are more easily operated without smoke than the plain furnaces.

c Almost any hand-fired furnace may be operated by means of steam jets so as to produce but little smoke.

d While all of the above may be accomplished with a skilled fireman, such plants cannot be depended upon for smokeless results at all times.

e Stokers without suitable combustion chambers or when improperly operated may be expected to smoke.

f Experience has demonstrated that the best stokers properly installed are superior to hand-fired furnaces for economy and smokelessness.

As will be seen from these results, it is possible to burn low volatile and low ash coals with nearly the same efficiency at moderate rates of combustion as may be expected with mechanical stokers when operated by firemen equally skilled. This condition makes it difficult to induce the owners of small plants to install stokers unless they do so for the purpose of reducing the smoke. In a large plant the expense of installing stokers is fully justified because of the saving in fuel and labor. They may in a sense be considered as part of the coal-handling

machinery. The large plant has the benefit of the best engineering talent in its design and construction, and of expert engineering advice and supervision throughout its period of operation. The economy in handling coal and ash, the economy due to a higher order of supervision made possible by the size of the plant, the reduction of labor, and the advantage of buying supplies in large quantities, reduce the cost of power. Incidentally, the plant may be operated with less smoke than a number of small units of the same horsepower located in individual plants.

The average business man does not maintain a power plant from choice but from necessity. If he were able to purchase heat as well as light and power he would gladly pay for service from a central station. This would relieve him of the main details connected with the management of his steam plant and would give him the space occupied by the plant for use in his regular line of business.

The growth of the central heating business has been rapid during the past five years in some localities, and there seems to be a tendency on the part of manufacturers and merchants to purchase heat in case it can be obtained at or near the figure which it costs them to produce it.

It is perfectly logical to expect a reduction of smoke within a few years due to the adoption of systematic plans for numerous heating and lighting stations so distributed in each large city as to serve the business districts with light, power and heat economically. These stations could probably be most economically operated if they generated only enough steam for heating and were arranged as sub-stations to take the excess electric current required from a central power house so located as to generate current at the lowest cost.

CONCLUSIONS

The smoke from power plants may be greatly reduced by adopting the following methods:

a Use low volatile coals or mixtures of bituminous coal with coke or anthracite in all hand-fired furnaces. Use steam jets if necessary to prevent smoke at high rates of combustion.

b Use automatic stokers in all plants in which the expense can be offset by the saving due to better combustion, a reduction of labor and the use of cheaper fuel.

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FURTHER DISCUSSION

E. G. BAILEY. Although the Ringelmann smoke chart has be used for many years as a standard of measurement, it has o recently received the attention which it deserves. The error caused the personal factor of the observer, which is much smaller tha generally believed, is due to the color of the smoke being someti of a brownish cast as compared with the jet black ink used in mak the charts. It must be remembered that smoke corresponding

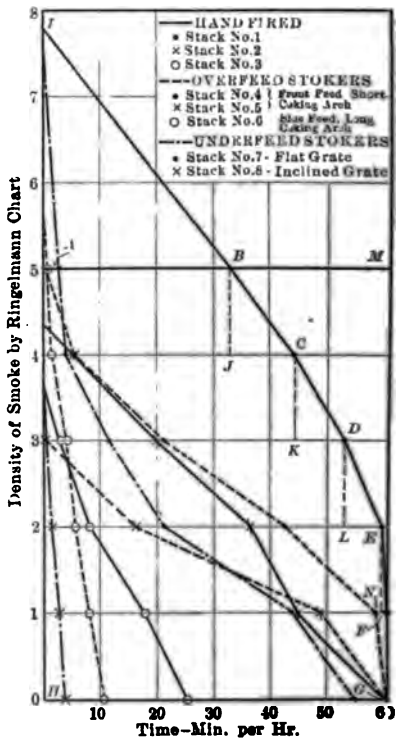


FIG. 1 PLOT OF OBSERVATIONS GIVEN IN TABLE 8

No. 1 must allow 80 per cent of light to pass through it; No. 4 p 20 per cent of light; No. 5 is opaque regardless of exact mat of color shades.

When comparing smoke with the chart, the density of s should be as dense as or denser than the number assigned it, ye so dense as the next higher number. For instance, if smoke is d

than No. 3, and not so dense as No. 4, it should be recorded as No. 3. Likewise, if smoke being emitted from a stack is not so dense as No. 1, it should be recorded as − 1 or + 0. The density of the smoke is obtained by averaging all readings and expressing the result in percentage of smoke on the basis of No. 5 being 100 per cent, but this method gives very little idea of the nature of the smoke. Ringelmann chart readings are usually taken at ½-min. or 1-min. intervals during the period of an hour or more and the readings plotted in the form of a log. The plotted continuous log gives a very good general idea of the manner and regularity of the smoke emission, but it is very unsatisfactory for comparing one stack with another, or the same stack from time to time.

An additional method which the writer has used to good advantage for several years is to plot a series of readings as one characteristic curve. This is done by adding the total number of readings of each different density and reducing them to a basis of minutes per hour. To the number of minutes corresponding to each density are added all the minutes corresponding to the greater densities. Ringelmann chart numbers are then plotted as ordinates, and minutes as abscissae. For example, in Fig. 1, stack 7, the readings of a 2-hr. period reduced

TABLE 8 SMOKE OBSERVATIONS—STACK 7

Density, Ringelmann Chart No.	Smoke of Each Density Emitted, Min.	Smoke of Each Density and Darker Emitted, Min.
5	2.5	2.5
4	1.0	3.5
3	8.0	11.5
2	9.5	21.0
1	23.0	44.0
−1 or +0	10.5	54.5
0	5.5	60.0
	Total 60.0	

to minutes per hour were as shown in Table 8. The values in the last column are plotted as abscissae on the lines corresponding to the different density numbers, and the curve drawn through these points indicates the general character of the smoke being emitted.

The curves in Fig. 1 represent a variety of plants located in different places with various equipment, but all burning semi-bituminous coal with volatile matter between 17 and 21 per cent. Most of these data were obtained in connection with the drafting of the smoke bill

recently enacted for Boston through the effort of the Fuel Supp
Committee of the Boston Chamber of Commerce. Detailed inf
mation relative to the rate of combustion, number of boilers in ope
tion, flue gas analysis, etc., is lacking in these cases, but they
given to show the different characteristics of different equipm
and operating conditions.

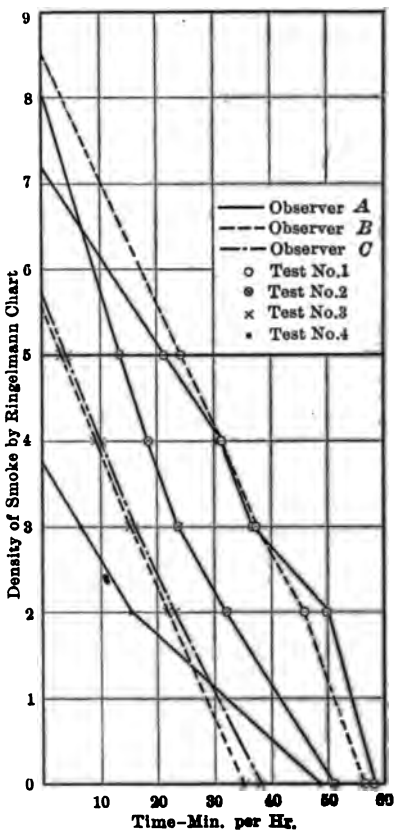


FIG. 2 CHARACTERISTIC SMOKE CURVES FROM INTERNALLY-FIRED BOIL

Stacks 1, 2 and 3 (Fig. 1) are connected with hand-fired boil
and the curves show the same general rate of gradation, but the
a great difference in the total amount of smoke produced from e
Stack 1 emitted No. 5 smoke for 33 min.; No. 4 smoke and dar
44½ min.; No. 3 smoke and darker, 53 min.; No. 2 smoke and dar
59½ min.; and No. 1 smoke and darker, 60 min. per hr. No. 5 or

Ringelmann chart includes all smoke that is opaque, and for a stack of a given diameter a certain amount of carbon particles per cubic foot is necessary to make this smoke opaque, but twice as much carbon or smoke could be carried per cubic foot of gas without changing the readings. This point is graphically brought out in these characteristic smoke curves. For instance, stack 1 would not be likely to produce smoke of No. 5 density, no more or no less, for 33 min. out of 1 hr., but during a part of this time it is undoubtedly much denser, as indicated by projecting the curve back until it intercepts the zero line at a density of eight. The exact nature of the extended

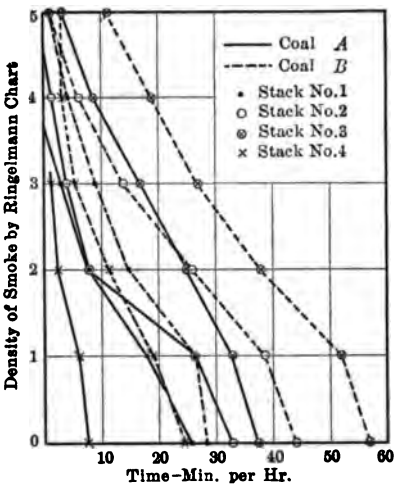


FIG. 3 SMOKE EMITTED FROM FOUR DIFFERENT STACKS ON TWO 11-HR. TESTS

part of this curve is problematical, but it illustrates the point that the average density of smoke may be much greater than is indicated by merely averaging the readings in the usual method. The average density of smoke, as compared with No. 5 by the Ringelmann chart as a basis, is the area *HIBEG* divided by *AMGH*, or 103 per cent. (Fig. 1).

If the area representing smoke denser than No. 5 is neglected, we have area *ABEGH* divided by *AMGH*, or 87.8 per cent. If the usual method of averaging smoke readings, such as was apparently used in the U. S. Geological Survey Bulletin No. 373, be applied to this stack we get only 83.3 per cent. This error is due to the omission of the triangular areas *BJC*, *CKD*, *DLE* and *ENF*, which properly belong in the area representing the total smoke emitted. All of the No. 4 readings representing the $11\frac{1}{2}$ min. from *J* to *C*, were as dense

as or denser than No. 4, and less dense than No. 5, so they would naturally be distributed along the diagonal line *BC*, and the same holds true with respect to the other parts of the curve. Applying the averaging method to the curve representing stack 5 (Fig. 1), 21.8 per cent of smoke is obtained, while the true average from the area is 31.8 per cent. The flatter the curve, the greater is the error caused by the use of the averaging method as usually applied, and the result is always too low.

Stacks 4, 5 and 6 are connected with stoker furnaces of the overfeed type, the first two having short coking arches with front-feed. The plants are similar with respect to the number of boilers and size

TABLE 9 GENERAL DIMENSIONS AND EQUIPMENT OF EACH STACK

Stack	Stack Diameter, Ft.	Number of Boilers Connected	Type of Boilers	Total Rated Boiler, H.P.	Total Grate Area, Sq. Ft.	Method of Firing
1	8	6	h.r.t.	900	204	hand-spreading
2	7½	8	h.r.t.	1200	272	hand-spreading
3	4	1	porcupine	300	56	hand-spreading
4	7	7	.....	1050	235	hand-spreading

of stack, but the relative rates of combustion, volatile matter in coal, etc., are not known. Stack 6 had only one furnace of side-feed type with a long coking arch connected with it. Stacks 7 and 8 are connected with underfeed stoker No. 7, having five stokers with flat grates, and stack 8, having three stokers of the inclined grate type.

No specific conclusions as to the value of the different methods of firing should be drawn from the curves in Fig. 1, since they are merely given to show the great variation that exists in actual practice between plants with similar equipment.

The characteristic smoke curves in Fig. 2 were all taken from the same stack connected with an internally-fired boiler of the locomotive type. The same kind of coal was fired by the same fireman, using the spreading method, in each test. The only changes made on the different tests were in the amount and temperature of secondary air supply. The coal used on these tests contained about 30 per cent of volatile matter, and over 50 lb. of it were burned per square foot of grate per hour.

The agreement between different observers is shown in Tests 1 and 3. Observers *A* and *C* had had very little experience in the use of

the Ringelmann chart, and neither knew that observer *B* was taking readings.

The curves in Fig. 3 represent the smoke emitted from four different stacks at one plant on two 11-hr. tests made on consecutive

TABLE 10 GENERAL DATA REGARDING SMOKE PRODUCED

		A	*B*
a	Coal fired		
b	Analysis of coal	Per cent	
	(1) moisture	4.81	5.40
	(2) volatile	16.22	18.81
	(3) fixed carbon	70.40	69.00
	(4) ash	8.57	6.97
	(5) sulphur	1.20	0.70
c	B.t.u.	13,639	13,838
	Boilers of Stack	In. of Water	
d	Average draft in firebox 1	0.45	0.31
	2	0.25	0.32
	3	0.30	0.32
	4	0.21	0.27
		Lb.	
e	Coal fired per sq. ft. grate per hr. 1	15.1	13.8
	2	11.9	11.8
	3	19.6	16.5
	4	9.2	11.7
		Per cent CO_2 Volume	
f	Flue gas analysis CO_2 1	8.1	7.7
	2	6.9	7.4
	4	7.4	9.5
		Per cent CO Volume	
g	Flue gas analysis CO 1	....	....
	2	....	0.05
	4	....	0.20
		Per cent	
h	Air excess from flue gas analysis 1	137.0	146.0
	2	180.0	149.0
	4	155.0	87.0
i	Smoke with No. 5 on Ringelmann chart as 100 per cent, from Fig. 3 1	13.8	22.8
	2	18.2	35.8
	3	34.7	56.0
	4	4.3	17.2

days. The tests were primarily made to determine the comparative values of the different coals from the evaporation on the entire plant, and the firemen gave no attention whatever to the amount of smoke made.

Table 9 gives the general dimensions and equipment connected with each stack, and Table 10, the general data which have direct bearing on the amount of smoke produced. All conditions were maintained as nearly uniform on the two tests as the daily operation of the plant would permit, the only intended change being in the coal burned. The principal difference between the coals so far as smoke is concerned is in the percentage of volatile matter, which was 16.22 and 18.81 in coals *A* and *B* respectively as fired, or 17.04 per cent and 19.88 per cent on the dry basis. Owing to changes in the draft and the amount of clinker formed, the rate of combustion was not quite the same for the two tests. There was also some change in the flue gas analysis and air excess. The gas samples were taken from the main flues and included considerable leakage of air through the boiler settings. No gas analysis was made from stack 3.

The curves in Fig. 3, and *i* (Table 10) derived from them, indicate the increased amount of smoke due to an increase of 2.8 per cent in the volatile matter. The increase in smoke from stacks 1 and 3 was proportionally less as compared with the increase from stack 2, owing to the lower rate of combustion in stacks 1 and 3 with coal *B*, as compared with coal *A*, while the rate was practically the same for both coals in stack 2. The amount of smoke from stack 4 was four times as much with coal *B* as with coal *A*, due to an increase in the volatile matter of the coal, rate of combustion and decrease in the excess of air.

Slight differences in the percentage of volatile matter, rate of combustion, air excess, method of firing, etc., are found to have a marked effect upon the amount of smoke produced when the characteristic curves are drawn. By the use of such data and curves, it is possible to determine the relative importance of the different factors affecting this problem, and to take intelligent steps to reduce the density of smoke to the desired limits.

The time and density limits incorporated in the law for the abatement of smoke recently enacted for Boston and its vicinity have been worked out along this line and are possible of attainment in everyday practice if the conditions of individual plants are properly studied and changes intelligently made.

FREDERIC H. KEYES said that the power plants of New England are so situated that the use of anything but bituminous coal is impossible; and unfortunately the price is usually the controlling factor rather than the quality, a fact largely responsible for the amount of smoke. Some of the largest users of bituminous coal have already found it advantageous to buy their coal under specifications especially drawn up to meet their requirements. This would seem to be the first step in the right direction, so far as smoke is concerned. The next step is to fire and burn it properly. Here the coöperation of the fireman is absolutely necessary. If he could be induced to regard the problem from the standpoint of the man who pays the bills the results would be entirely satisfactory. From personal experience and observation he knew that in plants where a good system of firing was followed, satisfactory results were obtained with a reasonable amount of supervision and without any other special devices. Next to the fireman the quantity of air, together with the manner and conditions under which it is mixed with the products of combustion, is of the greatest importance. This is a point which must be determined for each individual case according to the kind of coal used and the general conditions governing the operation of the plant. It is a fact that under favorable conditions a good grade of bituminous coal can be burned without making smoke, and under other conditions the results are satisfactory if mixed with anthracite screenings or coke breeze. It is believed that special devices such as steam jets and fire-brick arches, with few exceptions, usually cost more to operate and maintain than can be saved through the use of low grade fuel, for which some such special device is almost always required in order to obtain even approximately satisfactory results. While it is believed that greater care in the purchase of coal and the setting of boilers will accomplish much in the way of preventing smoke, more can undoubtedly be done by educating the fireman to the proper use of the fuel given him.

CHARLES H. MANNING. The use of underfeed stokers deserves more consideration than Mr. Randall gives it, not so much for smoke prevention as for economy. Such stokers heat the fuel slowly and the hydro-carbons are gradually gasified, which allows of their combustion as they pass up through the incandescent layer of fuel above them; whereas in hand-firing they flash into gas as the coal is thrown on top of the fire, and pass off largely unconsumed, increasing the smoke. It is true that these stokers are used to less advantage in

power plants running intermittently since they smoke when the furnace door is opened during the last hour of the run to break down the fire.

It is believed that with hand-firing the fixed carbon is a better guide to the value of the fuel than the British thermal units, which are a useful guide, however, for underfeed stokers.

HENRY BARTLETT. I wish to speak of the problem of smoke abatement from the standpoint of the railroad man, giving some of the reasons for making smoke, the difficulties in mitigating it, and some of the remedies applied.

We have, in the locomotive itself, an overworked power plant. The boiler is restricted in dimensions, operated under forced draft at all times and compelled to burn 100 lb. or more of coal per square foot of grate per hour as compared with the stationary plants burning 10 or 20 lb. The locomotive boiler is called upon for ranges of work greater than that of any other service. One moment the locomotive may be quietly standing in the roundhouse with the banked fire and only 40 or 50 lb. of steam on the boiler, and within an hour it may be running on the road with its 200 lb. of steam and exerting its maximum power. It may be moving along and handling its heavy train, emitting little smoke, when the next moment it is suddenly stopped by a signal or flag, or required to take a siding to meet an opposite train. Under such changes it is impossible to eliminate the smoke, since the large body of coal necessary to perform the work keeps on emitting the volatile gases until they have disappeared. The terminals of runs are necessarily in large cities and here the locomotives are housed and have their fires cleaned and built up, all of which involves dirt and smoke. For these reasons it is impossible to burn bituminous coal in locomotive service without some smoke.

The only smokeless fuels available are anthracite coal, coke and oil. Should the railroads resort to the use of the first, the supply would be insufficient, since Pennsylvania mines only 70,000,000 tons annually, or less than the amount of coal consumed by the locomotives per year, and secondly, the price would so advance as to render the cost prohibitive. While coke is smokeless, that is its principal claim for merit, since on account of its other qualities, it has only about 80 per cent of the efficiency of bituminous coal. Oil properly fired is a smokeless fuel and is largely used by the railroads adjacent to its source, but it is also limited in supply and the cost of its transportation would make it prohibitive for general use. Smoke-consuming

levices have so far been unsuccessful and the only thing of this kind n use today is the brick arch, which increases the course of the gases nd delays their departure from the firebox, thereby assisting in heir combustion.

I believe the real and only solution of the smoke problem is the ducation and supervision of the engineer and fireman. It is a oint problem between the two, for negligence on the part of one an defeat the good efforts of the other. This education on a big ailroad is a great problem and involves the continuous efforts of a arge number of officers. The railroads are at all times putting forth very energy and sparing no expense to reduce smoke to a minimum. as a result I believe I am safe in saying that great improvement has een made.

GEORGE H. BARRUS. The gases first evolved from a charge of coal rown on a hand-fired furnace are in their original cold state. Con- act with the hot atmosphere and radiant heat of the furnace increases ne temperature of the exposed portions of the gases sufficiently to nite them, and these take fire and burn away. Portions of gas hich are not favorably exposed receive an insufficient quantity of eat to become thoroughly ignited, and these pass out of the fur- ace in an unconsumed state. It is the unheated gas thus formed hich causes smoke, and the whole problem of smoke prevention lies overheating, so to speak, these gases before leaving the combustion namber, so that they will ignite. When these gases receive a roper amount of heat before reaching the boiler, they are burned ithout smoke, and the degree of smokelessness obtained depends on ne degree with which the heating of the gases has been effected.

This feature of the subject may be illustrated by referring to an xperiment I have made on a battery of two 300-h.p. vertical-pass hori- ontal water-tube boilers. The result aimed at was to ascertain the ffect of firing the two boilers alternately and employing the incandes- ent coke of one furnace as a medium for overheating the gases evolved om fresh charges of coal in the other. An opening was cut through ne intermediate wall between the two furnaces, extending horizon- ally the whole length of the grate and vertically to the lower row of ubes, putting the two furnaces into free communication. The clos- g of either of the flue dampers was sufficient to cause the products combustion from the furnace of one boiler to pass through the inter- ediate opening and over the fuel bed of the other furnace, and nereby to secure the desired object. To make a comparison of the

smokelessness of this system with the ordinary system of operation the boilers were first run in their usual manner. The coal was New River and one boiler was fired at a time. The firing system employed consisted in charging the two outside doors first, there being three doors in all for each boiler, and then waiting a short time before charging the middle door.

Smoke observations were made every minute for a continuous period of two hours, the estimated percentage of black smoke being judged as it appeared to the eye when escaping from the top of the chimney. With the boilers operated in the ordinary manner, the average amount of smoke observed for the entire period of 2 hr., including the time when there was no smoke, was 13.6 per cent. The maximum amount was 75 per cent, and for 54 min. there was an entire absence of smoke, or only a trace of it.

When the alternate system was brought into use, the three doors of each boiler were fired in rotation, there being no wait between doors. Smoke observations showed that the average amount of smoke during the entire period of 2 hr., including the time of no smoke, was 2.3 per cent. The maximum amount was 10 per cent, and for 1 hr. 22 min. there was an entire absence of smoke, or only a trace of it. It will be observed that the latter method produced a marked effect upon the character of the smoke, reducing its density and the length of time it was visible. It may be added that the smoky flame leaving the new coal was seen by actual observation to clear up immediately on passing into the secondary furnace.

JOHN T. HAWKINS. There can be very little doubt that the suppression of smoke is a desideratum and a great one, if it is for physical reasons only; but there has been, I think, a great deal of exaggeration as to the economy of smokeless combustion. In the products of combustion from bituminous coal, there not only are losses from fixed carbon, the real smoke, but from uncombined carbon in the form of CO. As far back as 1874 or 1875 there was great furor in and around New York about reducing the smoke from soft coal, and many extravagant claims were made as to the losses in burning bituminous coal. Theron Steel, a graduate of the first class of engineers from the Naval Academy, and myself conducted in 1874 and 1875 in New York a series of experiments to determine what was the difference in economy between the heaviest, smokiest firing that could be made and absolutely clear, smokeless firing with bituminous coal. The apparatus was especially prepared and set up in such a way that

ctly transparent white-hot gases could be made to pass out of
ombustion chamber and the boiler tubes with no sign of smoke
ıg from the chimney at any time. We could also fire for an
me amount of smoke. There were peep-holes arranged to permit
xamination of the character of the combustion and of the escap-
ases. All kinds of coal were used, and the analyses were exhaus-
in every way. The results were that we found that between the
smoky fire we could make by hand-shovel firing, and the clear
:eless fire, there was never more than a loss of about 0.7 of 1
ent, more than half of which was due to the increased escape of
which always obtained with smoky firing. The greatest actual
)f fixed carbon was, therefore, only about 0.3 of 1 per cent, which
's that the economy feature of the smoke problem is of little
ırtance.

this loss were as great as Mr. Randall quotes in his paper (3 to
· cent) attempts would have been made long before 1874 or 1875
ɔ away with bituminous smoke, and the question would today
much more agitated one than it really is.

IAS. H. BIGELOW. In looking over some old drawings dating as
ack as 1785, we find that smoke abatement is not a new problem,
one that inventors have been working on ever since that time,
many and varied are the methods suggested for decreasing it.
mes Watt in 1785 proposed hot funnels or pipes filling the space
'een the top of the bridge wall and the bottom of the boiler; J. & J.
:rton in 1800 introduced tubes in the front wall to admit cold air
the fire. In 1809 to 1812, perforated pipes located in the bridge
and extending through the side walls were tried. A little later,
ıods of introducing air from the ash pit through the bridge wall
baffles back of the bridge wall were experimented with. In
), W. Losh proposed to divide the fire longitudinally and to pass
gases from one fire under the grate of the other. In 1838, D.
:tham introduced a fan to draw the gases from the back of the
ge wall and to mix them with fresh air blowing them again through
fire. A deflecting arch over the fire was tried by R. Rodder in
). A coking plate in front of the furnace was designed by
/ard and Sons, in 1840. J. Smethurst planned to draw the gases
ugh a water chamber back of the bridge wall by means of an
ıust fan. J. Nutt placed a small secondary boiler back of the
ge wall to be heated by the gases, discharging the steam produced
the hot gases through a perforated pipe thus furnishing oxygen,

the gases being mixed by numerous baffle walls. In another method proposed by Johnson, a water tank divided into four sections is located back of the bridge wall and the gases deflected on the surface of each section by hanging walls. The water is thrown into the current of gases in the form of a spray by dash wheels, and is combined chemically with them. Many other methods were proposed from time to time including two grates in series and one above the other, also many different methods of introducing air into various parts of the combustion chamber and behind the bridge wall.

D. T. RANDALL. Nearly all these statements have been based on observations and experience with a particular apparatus and with fuels of the same general character. The various experiences in individual plants only emphasize the fact that burning bituminous coal efficiently without smoke is as important a problem as any which claims the attention of mechanical engineers.

It is possible to operate some plants smokelessly and at the same time inefficiently. Many plants are so designed that when operated to secure the highest economy, some smoke will be emitted from the stack and only a slight change in the conditions in the boiler room will cause them to smoke badly.

General conclusions regarding the smoke problem should not be based upon such plants alone. There has been considerable progress made in the design of furnaces during the past five years and there are many plants now operating in which bituminous coal is burned efficiently and without objectionable smoke.

No. 1297

THE TRANSMISSION OF HEAT IN SURFACE CONDENSATION[1]

By George A. Orrok, New York
Member of the Society

Ever since the first use of steam in the arts, the condenser has been a very important part of the machinery designed for its utilization and the very simple laws governing condensation by mixture were early understood and formulated. With the advent of the surface condenser the problem became more complicated and the laws governing the transmission of heat through tubes or plates from wet vapor or condensing steam to water have been investigated by many physicists from Poisson in 1835, Peclet in 1841 and Joule in 1861 down to the present time. The earliest statement of the law of heat transmission in solids was made by Newton in 1690, while most of the mathematical work has been based on Fourier's classic published in 1832. Most of the earlier experimenters were misled by defects in their apparatus but by 1870 the existence of the gas film on the steam side of the tubes was suspected. The existence of the water film was suspected as early as 1861. Sir William Thomson stated in 1880 that the work of the earlier investigators was vitiated by the assumption that the temperature of the metallic surfaces was the same as the temperature of the medium in contact with them.

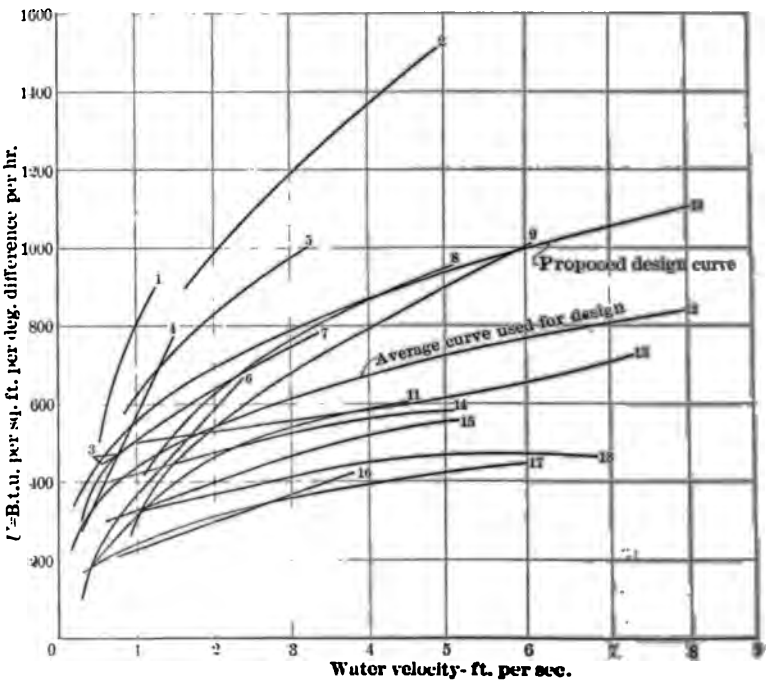
2 Since 1880 there have been attempts to ascertain the laws of heat transmission for condenser practice by many investigators: Werner and Hagemann in 1883, Ser in 1887, Richter in 1899 and Hepburn in 1901. The later experimenters have worked with actual machinery along what might be termed commercial lines.

3 The present status of the transmission of heat through metallic tubes from condensing steam to water according to various authorities may be stated as follows:

[1] For list of Symbols used see Appendix No. 1

Presented at the Annual Meeting, New York 1910, of The American Society of Mechanical Engineers.

a The quantity of heat transmitted by a unit of surface in unit time is proportional to the temperature difference (Joule, Rankine and most of the experimenters) or to the square of the temperature difference (Werner, Grashof and Weiss) between the media on the different sides of the tube.



1—Josse—top of condenser
2—Josse—top of condenser (with baffles)
3—Richter—corr. copper tubes (horiz.)
4—Hepburn—corr. copper tubes (horiz.)
5—Josse
6—Hepburn—plain copper tubes (horiz.)
7—Ser
8—Weighton—plain tubes
9—Josse
10— $U = 22 \sqrt{V_s} \sqrt[3]{0.022 + V_w}$ (V_s = 5)
11—Hagemann
12— $U = 17 \sqrt{V_s} \sqrt[3]{0.022 + V_w}$ (V_s = 15)
13—Nicol—horizontal tubes
14—Stanton—water flowing down
15—Stanton—water flowing up
16—Allen—horizontal tubes
17—Joule
18—Nicol—vertical tubes

FIG. 1 VARIATION OF HEAT TRANSMISSION WITH WATER VELOCITY

b The quantity of heat transmitted is proportional to some power of the water velocity ($V_w^{\frac{1}{3}}$ by Joule and Ser, $V_w^{\frac{1}{2}}$ by Hagemann and Josse, V_w^{1} by Stanton).

c The quantity of heat transmitted is proportional to some power of the steam velocity or mass flow ($V_s^{\frac{1}{2}}$ by Hausbrand and Ser, mass flow by Jordan).

d The quantity of heat transmitted is greatly affected by the amount of non-condensible vapors on the steam side of the tube (Bourne, Smith, Weighton, Morison, McBride).

4 These differences of opinion did not trouble designers seriously as long as small condensers and vacua of over two pounds absolute were the rule, but with the development of the turbine the need arose for condensers capable of condensing more than 200,000 lb. of water per hour at an absolute pressure of less than one pound. At first, excessive amounts of surface were installed, but the first cost and upkeep led to more careful design and the demand for a more accurate knowledge of the laws of heat transmission under condenser conditions.

5 A careful study of the results of all available experiments was made and plotted in Fig. 1. These curves show wide variation of values, but for a time the attempt was made to work from an average curve deduced by giving weights to the various experiments depending on the number of individual figures and their consistency. This average curve was used in the design of a number of large installations with excellent results.

6 The need for a careful determination of the whole question still existed and through the liberality of the management of The New York Edison Company the author was enabled to develop the apparatus and make the experiments described below, the results of which confirm and complete much of the work of earlier experimenters. It is hoped that they will aid condenser designers in producing apparatus better suited to the work, more satisfactory and more economical than ever before.

METHODS AND APPARATUS

7 The object in making these tests was to determine the heat transfer through various kinds of condenser tubes and the laws governing its variation under different conditions of steam temperature, pressure and velocity; velocity of circulating water; and mean temperature difference.

8 In order to obtain these data, a small surface condenser was constructed with a relatively small cooling surface and it was operated under conditions as nearly like actual condenser conditions as possible.

The steam inlet, dry vacuum, and circulating water lines were so arranged and controlled that any desired vacuum, any desired velocity of circulating water and any desired mean temperature difference could be maintained and that any one of these conditions could be varied through a considerable range quite independent of the other two. A hot well was constructed and so connected to the condenser that the temperature of the hot-well water (condensed steam) and its amount could be determined. Thermometers, pressure gages and a water meter were installed and a record was made of all desired data.

9 In order to fulfil these requirements, it was found necessary to make numerous changes in the apparatus as first constructed, which is shown in Fig. 2. It consisted of a condenser made of 5-in. extra-heavy wrought-steel pipe, with cast-iron screwed flanges on each end. To these were bolted cast-iron blank flanges, drilled and tapped for the various steam, water and vacuum connections. The condenser was of such a length that exactly 1 sq. ft. of cooling surface on a 1-in. outside diameter condenser tube was included between the inside faces of its end flanges. A condenser tube was passed through the center of the condenser and projected about 4 in. on each end through small stuffing boxes. These stuffing boxes, C_1 and C_2, are shown in detail in Fig. 4. A thermometer well and a vacuum gage connection were installed for recording the steam temperature and pressure. A hot well made of 5-in. wrought-iron pipe with a screwed and a blank flange on each end was connected to the condenser as shown. On the front of the hot well, a gage glass and a graduated scale were placed so that the height of the water could be observed and recorded, making it possible to calculate the weight of steam condensed for any given length of time. The valve G was used to empty the hot well at the end of a test. A thermometer was installed at H for observing the temperature of the condensed steam, the piping being so arranged that there was always a solid body of water surrounding the thermometer well. A $\frac{1}{2}$-in. line connected the top of the hot well to the vacuum line to equalize the pressures. The entire condenser and $\frac{3}{4}$-in. line to the hot well were covered with 4 in. of magnesia pipe covering to eliminate the effect of radiation.

10 The 1-in. circulating water line was taken from a 6-in. salt-water fire line in which was maintained a pressure of 90 lb. gage. This 1-in. line was connected to the condenser tube at each end by a piece of rubber hose which was wired at the ends to withstand a pres-

sure of about 20 lb. gage. Thermometer wells and thermometers were installed for observing the temperature of the circulating water at the inlet and the outlet of the condenser. The method of installing these thermometer wells is shown in detail in Fig. 3. A water

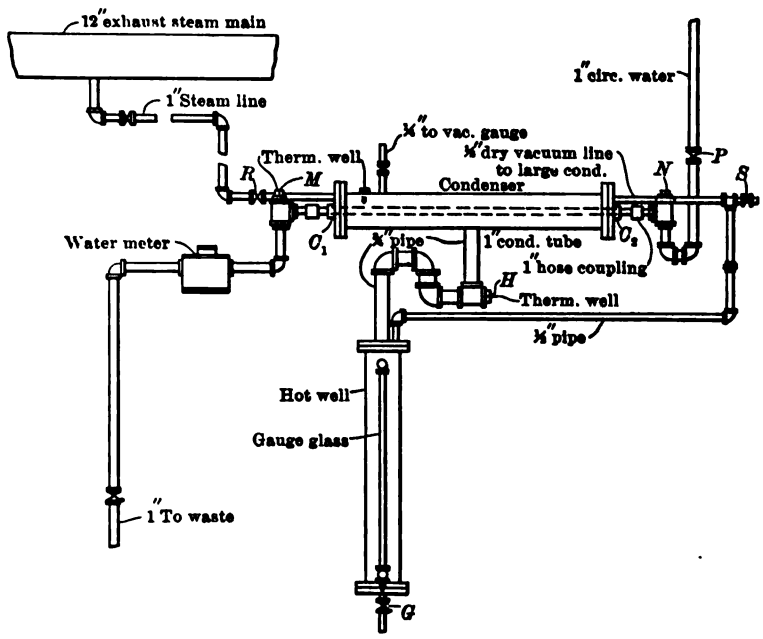


FIG. 2 APPARATUS AS FIRST CONSTRUCTED

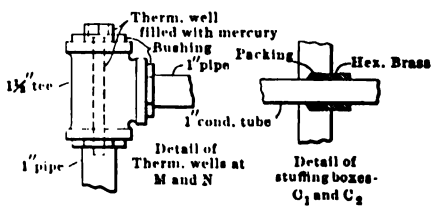


FIG. 3 FIG. 4

DETAILS OF APPARATUS

meter was installed to register the amount of water flowing. The valve P was used to regulate the rate of flow.

11 The 1-in. steam pipe was taken from the bottom of a 12-in. exhaust main which carried the exhaust steam from various auxiliary

engines to an open feed-water heater. The pressure in this line was about 2 lb. gage. The valve *R* was used to regulate the amount of steam admitted to the condenser.

12 The ½-in. dry vacuum line was connected to the hot well of a large surface condenser which was operated at a vacuum of from 27.0 in. to 28.5 in. of mercury, or about 1 lb. absolute pressure. All flanged joints were made up with ⅛-in. rubber gaskets and all screwed joints with a heavy coating of red lead on the threads. One of the greatest difficulties encountered when running tests at a high vacuum was the prevention of air leakage. This difficulty was overcome to a great extent by a frequent and liberal application of a special heavy asphaltic paint to all joints. It was found possible to hold a vacuum within 0.5 in. of mercury of that in the large condenser when all valves were closed, except valve *S* in the vacuum line. With *S* closed, this vacuum would only drop from 27 in. to 26 in. in a period of 5 min.

13 All thermometers used in these tests were of the best make and could be read with accuracy to 0.1 deg. fahr. The water meter used was tested at various times and its error determined for all rates of flow. All heat transfer tests were extended over a period of 10 minutes after conditions had become constant and readings of temperatures and pressures were taken every 3 minutes.

14 A series of tests was made on various kinds of tubes at different vacua, but it was found that the heat transfers calculated from these tests had a maximum variation of 20 per cent for the same tube under exactly the same conditions as to steam temperature and pressure, mean temperature difference and velocity of circulating water. In these tests the vacuum was varied by regulating the steam admitted through the valve *R*, the vacuum line being kept wide open. It was found that to maintain a higher vacuum than 24 or 25 in. of mercury, the steam valve *R* could be opened only a very small amount and that the steam entering the condenser was superheated as much as 50 deg. fahr. Another difficulty encountered was that at low vacuum, when the valve *R* was almost wide open, the heat transfer figured from the amount of steam condensed, as measured in the hot well, was considerably higher than that figured from the heat absorbed by the circulating water. This showed that the steam admitted must have contained considerable moisture. It was also found very difficult to maintain the rate of flow of the circulating water constant, due to the variation in pressure in the fire line from which it was taken. To overcome these difficulties, a number of

changes were made in the piping. A separator was installed in the steam line and the line was taken from the top of the 12-in. exhaust main instead of from the bottom. To aid in controlling the rate of flow of the circulating water, a pressure gage was installed in the line, and to maintain a constant rate of flow it was necessary only to keep this pressure gage indicating a steady pressure by regulating inlet valve *P*. In order to make it possible to maintain a high vacuum in the condenser without undue throttling of the steam, the dry vacuum line was increased in size to a 1-in. pipe.

15 Another series of tests was then made and it was found that the moisture in the steam at low vacua was practically eliminated. It was also possible to maintain a high vacuum, although there still seemed to be a more or less uncontrollable degree of superheat and the heat transfers for these high vacua tests were considerably lower than those at the lower vacua. A water jacket was now placed on the steam line with a ½-in. water connection from the circulating water line. This arrangement seemed to have but slight effect, however, and there was still found to be a considerable variation in heat transfer when an attempt was made to duplicate tests.

16 It was decided that the difficulty must lie with one of the following things:

a The quality of the steam as to amount of superheat, moisture, or entrained air and oil.

b The circulation or velocity of the steam.

c Air leakage.

d Cleanliness of the tubes.

17 To take care of the first item, it was decided to build a small independent boiler and generate steam as it was needed by means of a high-pressure steam coil. The boiler was constructed of two 14-in. flanged tees bolted together, with blank flanges bolted on the ends. It was connected to the condenser by a 5-in. pipe, the condenser being reduced in length and a 5-in. flanged tee bolted on one end, making the total face-to-face dimension the same as before. A steam coil, consisting of approximately 22 ft. of ¾-in. wrought-steel pipe, was placed in the boiler in such a way that it was entirely below the water level and still left a sufficient disengaging surface for the steam. Steam was supplied to this coil from a high-pressure steam main through a 1-in. pipe. Make-up water for the boiler was taken from a Croton water line through a ½-in. pipe. The bottom of the hot well was also connected to the boiler by a ¾-in. line containing a gate and a check valve so that the condensed steam could be returned

directly by gravity to the boiler. This arrangement obviated the necessity of breaking the vacuum and emptying the hot well after each test. A gage glass and a thermometer were installed, the whole apparatus being shown in Fig. 5*a*.

18 To take care of the second item, the vacuum line was increased to 2 in. A $\frac{1}{4}$-in. connection for a vacuum gage was installed at *E* and a $\frac{3}{4}$-in. valve opening to atmosphere at *F*. With this arrangement, for any desired opening of the valve *S*, a constant velocity of steam through the condenser could be maintained by regulating the air valve *F* and the valve *K*, so that the steam passing through the valve *S* had a constant drop in pressure. This drop, due to velocity of the steam, was considered to be the difference in pressure as read at *E* and *D*.

19 The subject of air leakage was investigated by closing all valves except *S* and *K* in the vacuum line, when it was found possible to hold a vacuum in the condenser practically equal to that in the large condenser. The valve *S* was then closed and observations were taken as to the rate of fall of the vacuum in the apparatus. It was found that the vacuum would only drop from 28 in. to 27 in. of mercury in 15 min. These air-leakage observations were taken before every series of tests.

20 In order that the condition of the tubes as to cleanliness should not affect the heat temperature, all tubes used for testing were thoroughly cleaned every 10 or 12 tests. A series of tests made with this remodeled apparatus under constant conditions was found to have a maximum variation of not over 10 per cent and an average variation of 3 or 4 per cent. In these tests, the vacua were varied by regulating the amount of steam admitted to the steam coil through the valve *T*.

21 Tests were run at vacua of 7, 15, 20, 25 and 27 in. of mercury, with circulating water at a temperature of about 40 deg. fahr. and a velocity of 8.6 ft. per sec. on the following kinds of tubes (tests 280 to 528 inclusive):

1 Admiralty
2 Admiralty, oxidized
3 Admiralty, vulcanized inside only
4 Admiralty, vulcanized outside only
5 Admiralty, vulcanized both sides
6 Admiralty, lead lined
7 Admiralty, old tube from condenser
8 Monel
9 Copper
10 Copper, aluminum lined
11 Aluminum bronze
12 Zinc
13 Tin
14 Cupro-nickel
15 Shelby steel
16 Glass

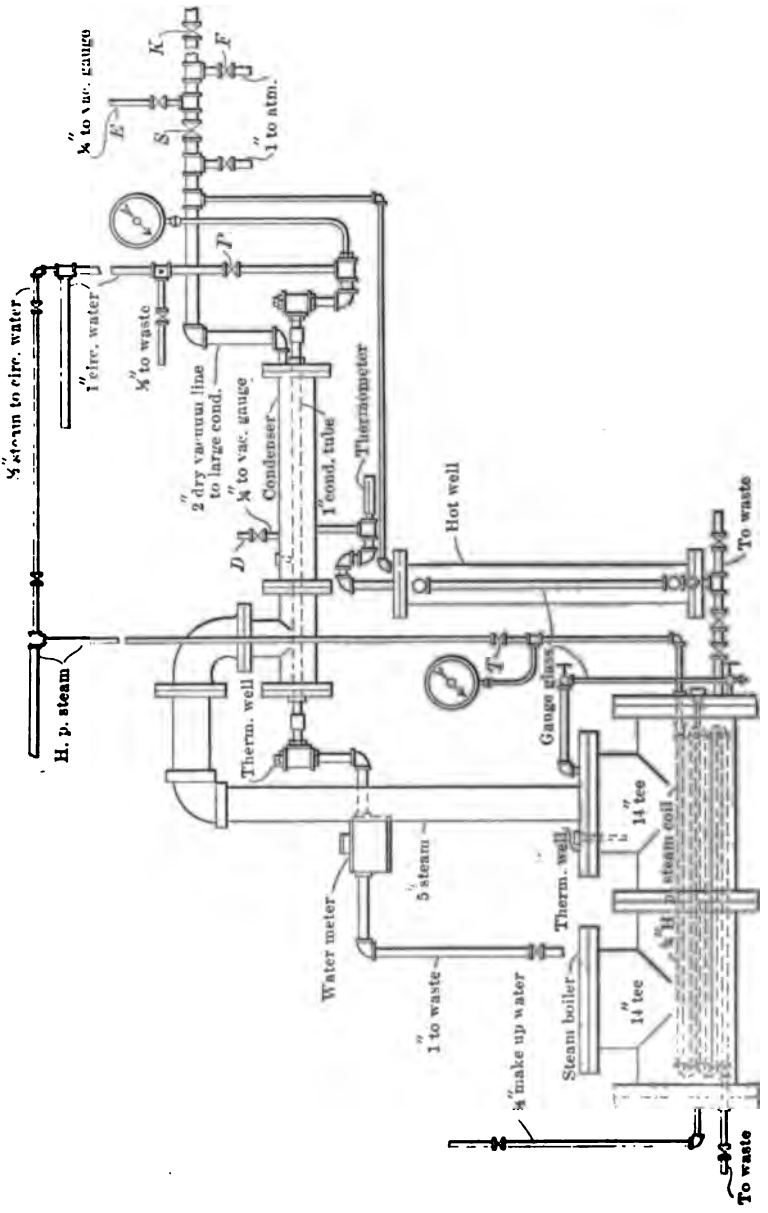


FIG. 5a APPARATUS AS ACTUALLY USED

The tests with the glass tube were difficult to make on account of the thinness and fragility of the tube and the tube was broken before all the desired tests were completed. In all these tests, it was found that the temperature of the steam was constant throughout the apparatus.

22 A series of tests was made on an Admiralty tube with a range in velocity of circulating water of from 1 to 11 ft. per sec. and a

FIG. 5*b* APPARATUS AS ACTUALLY USED

vacuum of 15 and 27 in. of mercury. In these tests the velocity of the circulating water was varied by regulating the valves at *P* and *V*, the pressure in the condenser tube being always kept above 10 lb. gage. All the above tests were made without changing the temperature of the circulating water, which was about 40 deg. fahr. (tests 529 to 622 inclusive).

23 To vary this temperature, a ½-in. line was installed connecting the high-pressure steam line to the circulating water line as shown in Fig. 5*a*. With this arrangement, it was possible to vary the temperature of the circulating water from 40 to 110 deg. fahr., thus varying the mean temperature difference without altering the other test conditions, and a series of tests was made on an Admiralty tube to deter-

FIG. 5*c* APPARATUS AS ACTUALLY USED

mine the variation of heat transfer with changes of mean temperature difference (tests 623 to 727 inclusive).

24 Finally, a series of tests was made on all the various kinds of tubes with circulating water at a temperature of 85 deg. fahr. and velocity of 8.7 ft. per sec. and a vacuum of 27 in. of mercury (tests 728 to 771 inclusive).

VARIATION OF HEAT TRANSFER WITH TEMPERATURE DIFFERENCE

25 After the apparatus had been working some time and had been giving consistent results, a set of approximately 100 tests (623

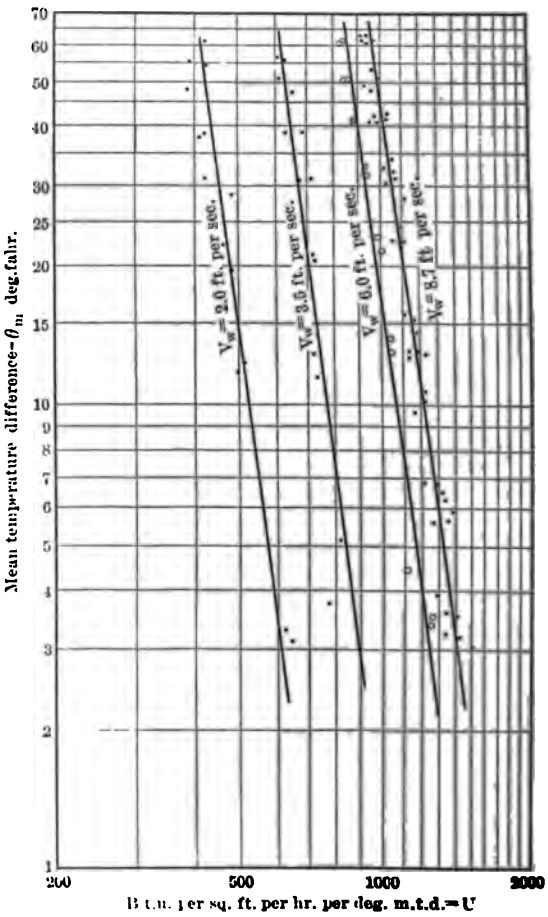


FIG. 6 RELATION OF COEFFICIENT OF HEAT TRANSFER TO TEMPERATURE DIFFERENCE

to 727) was run to determine the possible variation of the h transmission with the mean temperature difference. The quan ties of cooling water were so large that the temperature rise (t_1 - was always small and it was considered that the arithmetical m of the water temperatures and the steam temperature might

used without appreciable error in the calculation of the heat transfer. These tests were run at four different velocities, approximately 2, 4, 6, and 8 ft. per sec., the results were plotted on logarithmic paper and a smooth curve drawn through each set of plotted points. These curves were practically straight lines, as shown in Fig. 6, with a slope of about 0.125.

26 The relation may then be stated, $U = \frac{C}{\theta^{\frac{1}{4}}}$. Working from this, an expression may be obtained for the relation between the condensing surface or length of tube S and the temperature rise of the condensing water $(t_1 - t_0)$

$$S = C\left[(t_s - t_0)^{\frac{1}{4}} - (t_s - t_1)^{\frac{1}{4}}\right]$$

and the true mean temperature difference is

$$\theta_m = \left[\frac{\frac{1}{3}(t_1 - t_0)}{(t_s - t_0)^{\frac{1}{3}} - (t_s - t_1)^{\frac{1}{3}}}\right]^3$$

an expression which, in all practical cases, differs very slightly in numerical value from the geometrical mean

$$\theta_m = \frac{(t_1 - t_0)}{\log_e \frac{t_s - t_0}{t_s - t_1}}$$

27 The general expression connecting U and θ is then $U = \frac{K}{\theta^n}$, where n may have any positive or negative value excluding 0. The general expression connecting S and $(t_1 - t_0)$, will be

$$S = \frac{C_1}{n}\left[(t_s - t_0)^n - (t_s - t_1)^n\right]$$

and the true mean temperature difference is

$$\theta_m = \left[\frac{n(t_1 - t_0)}{(t_s - t_0)^n - (t_s - t_1)^n}\right]^{\frac{1}{1-n}}$$

For the case where $n = 0$ or $U = K$, a constant,

$$S = C \log_e \frac{t_s - t_0}{t - t_1}$$

and

$$\theta_n = \frac{t_1 - t_0}{\log_e \frac{t_s - t_0}{t_s - t_1}}$$

In Table 1 these values for U, S, θ_m and N (the total quantity of heat transferred) are tabulated and the curves of temperature rise and values of θ_m are plotted in Fig. 7 for certain steam and water temperatures.

TABLE 1 VALUES OF U, S AND θ FOR VARIOUS ASSUMED VALUES OF N

S = cooling surface in sq. ft.
N = $U\theta$ = total heat transfer per sq. ft. per hr. in B.t.u.
U = heat transfer per sq. ft. per hr. per deg. m.t.d.
θ_m = m.t.d. = mean temperature difference
Q = circulating water per hr. in lb.
K = a constant determined by experiment
t_s = temperature of steam
t_0 = temperature of circulating water at inlet
t_1 = temperature of circulating water at outlet
t = any temperature between t_0 and t_1

1	$N = K$	$U = \frac{K}{\theta}$	$S = \frac{Q}{K}\left[(t_s - t_0) - (t_s - t)\right]$	$\theta = t_s - \frac{t_1 + t_0}{2}$
2	$N = K\theta$	$U = K$	$S = \frac{Q}{U} \operatorname{Log}_e \frac{t_s - t_0}{t_s - t}$	$\theta = \frac{t_1 - t_0}{\operatorname{Log}_e \frac{t_s - t_0}{t_s - t_1}}$
3	$N = K\theta^2$	$U = K\theta$	$S = \frac{Q}{K}\left[\frac{1}{t_s - t} - \frac{1}{t_s - t_0}\right]$	$\theta = \sqrt{(t_s - t_0)(t_s - t_1)}$
4	$N = K\theta^{\frac{1}{2}}$	$U = \frac{K}{\theta^{\frac{1}{2}}}$	$S = \frac{2Q}{K}\left[(t_s - t_0)^{\frac{1}{2}} - (t_s - t)^{\frac{1}{2}}\right]$	$\theta = \left[\frac{\frac{1}{2}(t_1 - t_0)}{(t_s - t_0)^{\frac{1}{2}} - (t_s - t_1)^{\frac{1}{2}}}\right]^2$
5	$N = K\theta^{\frac{1}{3}}$	$U = \frac{K}{\theta^{\frac{1}{3}}}$	$S = \frac{8Q}{K}\left[(t_s - t_0)^{\frac{1}{3}} - (t_s - t)^{\frac{1}{3}}\right]$	$\theta = \left[\frac{\frac{1}{3}(t_1 - t_0)}{(t_s - t_0)^{\frac{1}{3}} - (t_s - t_1)^{\frac{1}{3}}}\right]^3$
6	$N = \frac{K}{\theta^{n-1}}$	$U = \frac{K}{\theta^n}$	$S = \frac{Q}{Kn}\left[(t_s - t_0)^n - (t_s - t)^n\right]$	$\theta = \left[\frac{n(t_1 - t_0)}{(t_s - t_0)^n - (t_s - t_1)^n}\right]^{\frac{1}{1-n}}$

28 Only two investigators, so far as I have been able to determine, have attempted experimentally to verify the law of the rise of temperature of condensing water in its passage through the condensing tube

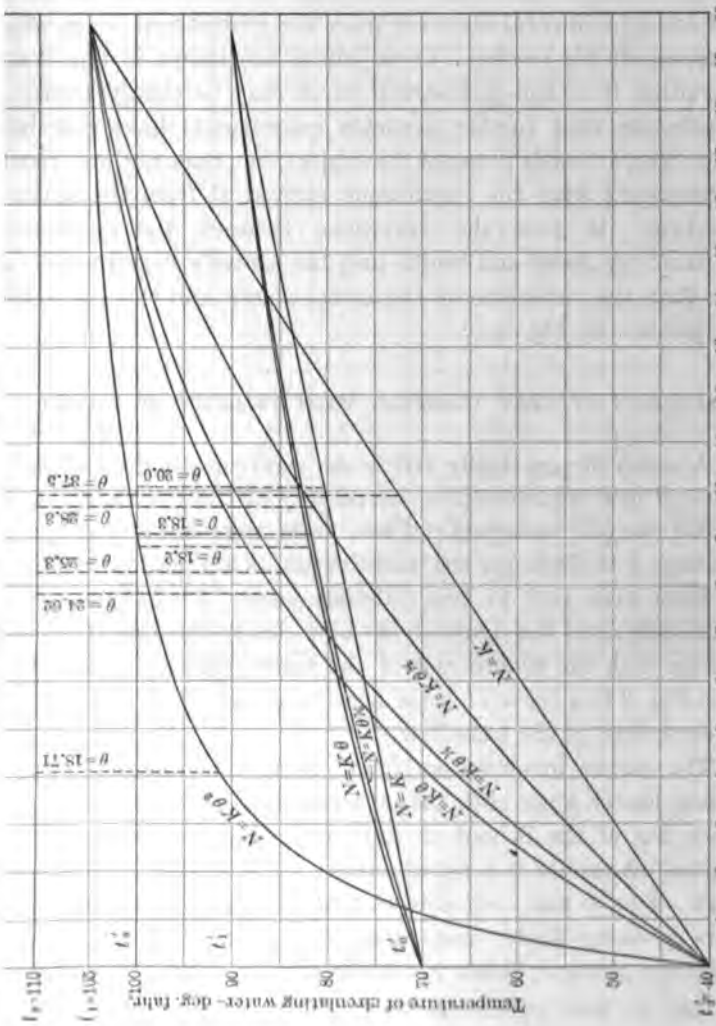


FIG. 7 CURVES OF TEMPERATURE RISE UNDER CERTAIN ASSUMPTIONS

J. Alex. Smith[1] experimented with a tube 6 ft. long, and Professor Josse[2] used a surface condenser approximately 86 sq. m. of surface. Neither experimenter gives his actual numbers but shows his results in a curve. Smith gives a second curve showing the deviation of his experimental numbers from the geometrical series which best represents his results. These curves are shown in Fig. 8 and the variation from the geometrical curve may be clearly seen. It is unfortunate that further accurate experiments have not been made on this particular phase of the subject, but none of these results are inconsistent with the conclusions arrived at from the author's experiments. In fact, the variations between the geometrical curve found by Josse and Smith and the writer's experiments are smaller than the variations of the actual points and the theoretical points plotted in Fig. 8.

VARIATION OF HEAT TRANSFER WITH VELOCITY OF WATER

29 A series of practically 100 tests was run to determine the variation of heat transferred to the velocity of the circulating water (tests 529 to 622 inclusive). These tests were run at various velocities from 1 to 11 ft. per sec. and the results are plotted in Fig. 9. These tests were run at two different vacua, 15 in. and 27 in. approximately, and the figure shows how closely the heat transmission varies with the square root of the water velocity. The third curve in Fig. 9 is a curve of total heat transmitted and apparently varies according to the same law.

30 The earlier investigators found somewhat different results. Josse and Foster have both taken advantage of the researches of Professor Ser of the School of Arts and Manufactures of Paris. Josse gives his results in a set of curves, while Foster gives a set of numbers. I have not been able to find the original figures. The numbers given by Foster and scaled from Josse's curves in metric measures are given in Table 2. From these numbers, Ser's experiments may be best represented by $U = 490\sqrt[3]{V_w}$, or, if the transmis-

[1] London Engineering, Mar. 23, 1906.

[2] Zeitschrift des Vereins deutscher Ingenieure, Feb. 27, 1909.

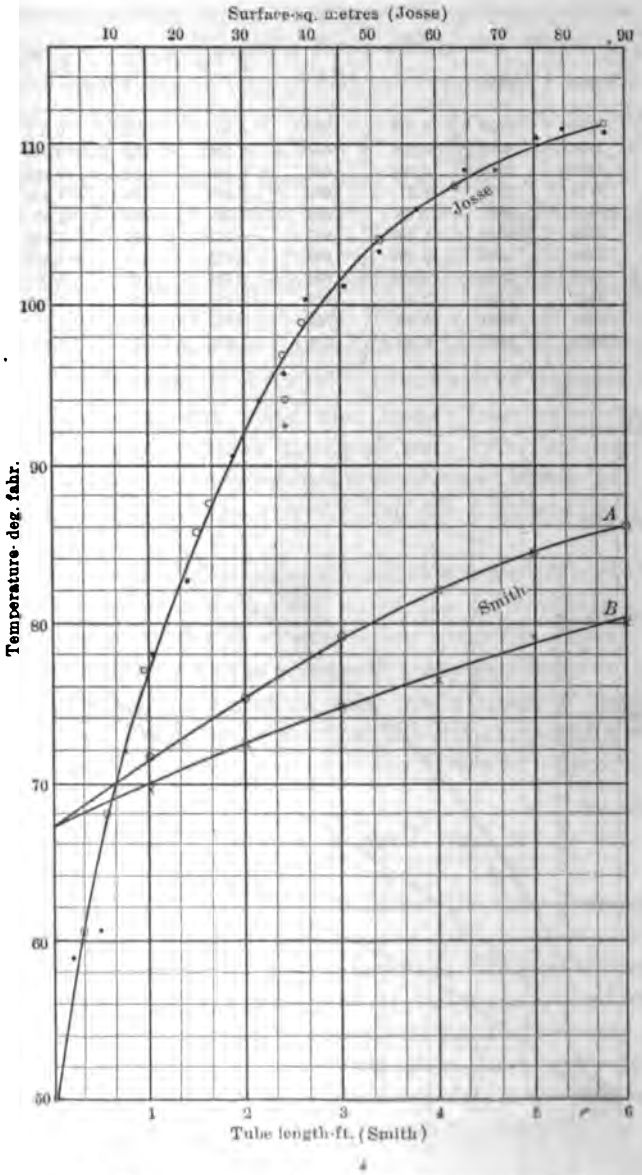


FIG. 8 EXPERIMENTAL CURVES OF TEMPERATURE RISE

TABLE 2 SER'S NUMBER FOR U

V_w m.	U cal. Foster	U cal. Josse	V_w ft.	U B.t.u.	$\sqrt[3]{V_w}$	C	$\sqrt{V_w}$	C
0.10	1400	1400	0.328	287	0.69	416	0.573	[illegible]
0.20	2300	2230	0.656	464	0.868	534	0.811	[illegible]
0.30	2550	2550	0.984	522	0.994	525	0.992	[illegible]
0.40	2710	2710	1.31	555	1.093	507	1.143	[illegible]
0.50	2860	2860	1.64	586	1.18	496	1.28	[illegible]
0.60	3020	3010	1.967	617	1.252	493	1.402	[illegible]
0.70	3180	3180	2.295	652	1.318	495	1.515	[illegible]
0.80	3330	3330	2.622	682	1.378	495	1.62	[illegible]
0.90	3480	3480	2.95	712	1.435	496	1.717	[illegible]
1.00	3640	3640	3.28	745	1.485	501	1.81	[illegible]
1.10	3800	3800	3.61	778	1.532	507	1.9	[illegible]

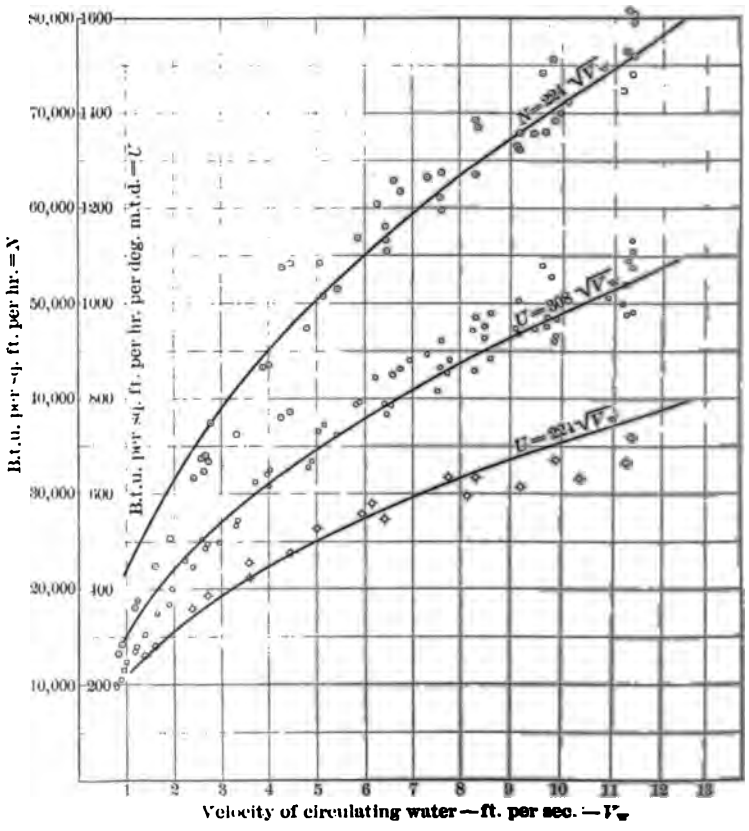


FIG. 9 VARIATION OF HEAT TRANSMISSION WITH WATER VELOCITY (ORROK)

ion corresponding to 0.328 ft. per sec. be neglected, $U = 508\sqrt[3]{V_w}$, he variations from the square root curve being much greater.

31 Josse has also published a curve giving the results of Joule's experiments which follows very closely the expression $U = 239\sqrt[3]{V_w}$. Joule's actual numbers are available and have been recalculated. The low-vacuum tests, up to 2.5 in. of mercury absolute pressure. follow very nearly the above figure, but the mean of all tests within condenser conditions is more nearly stated by the expression $U = 315\sqrt[3]{V_w}$.

32 The work of these two experimenters is widely known and has had nearly universal acceptance until within a very few years, when a number of authorities have claimed that the fact might be better expressed by the formula $U = C\sqrt{V_w}$. In support of this view, Hagemann's experiments were cited and Josse's own experiments on small-size condensers appear to agree well with this expression. Stanton deduced from his experiments at Owens College that U was directly proportional to the velocity, but his numbers have never been published.

33 The curves in Fig. 10 show the relation between heat transfer and circulating-water velocity for all of the experimenters whose work has been recalculated in connection with this paper. There may be some doubt as to the constant in any one case, but all the results from the curves are merely the true average of the experimental figures. It is probable that the critical velocity was exceeded in all cases.

VARIATION OF HEAT TRANSFER WITH VELOCITY OF STEAM

34 That the velocity of the steam across the tube surface has an effect on the transmission has been asserted by a number of authorities. Hausbrand and Ser have considered that the heat transmission was proportional to the square root of the steam speed. Jordan maintains that the transmission is proportional to the mass flow of the steam. Most of the other investigators have neglected this. In the experiments, we have been unable to detect any effect on the heat transmission which might be charged to the velocity of the steam approaching the tube surface.

35 Let us consider a condenser consisting of a single tube, through which the cooling water is flowing, surrounded by an atmosphere of steam. Condensation will take place at the outer surface of the tube and the steam will rush in to the tube from all sides. Meanwhile, the space surrounding the tube will attain a constant pressure

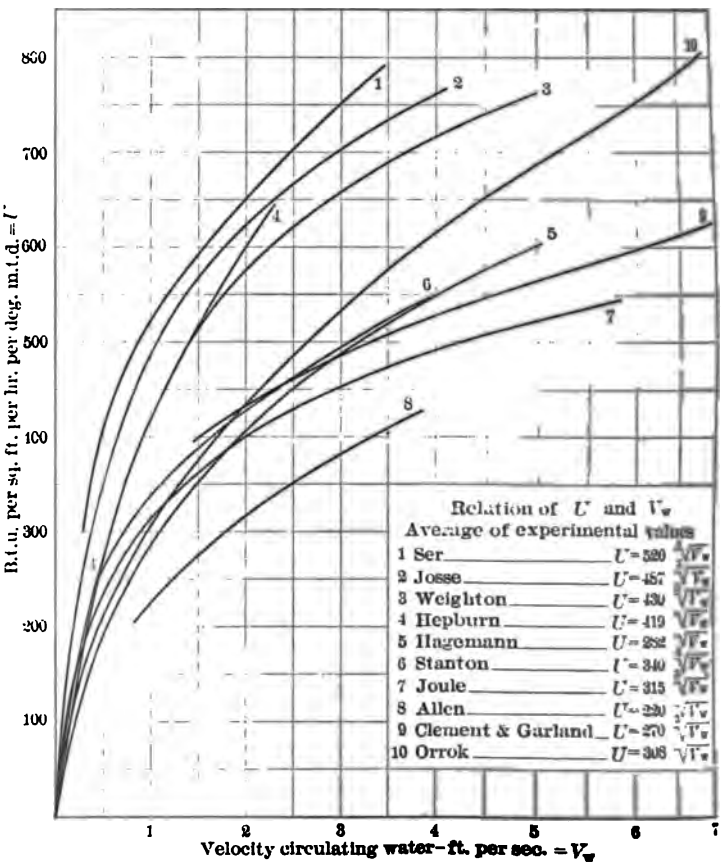


FIG. 10 VARIATION OF HEAT TRANSMISSION WITH WATER VELOCITY (VARIOUS AUTHORITIES)

due to the regular influx of steam into the condenser and its condensation on the tube. This constant pressure will determine the temperature of the steam and if there is no air leakage the temperature will be that due to the saturated vapor of water at the constant pres-

ure. It has been determined experimentally that the temperature nd pressure remain sensibly constant throughout the condenser, xcept for an exceedingly minute space in the neighborhood of the ube surface.

36 There is then a constant flow normal to the surface of the tube esides such residual velocity as may be in the steam after its passage

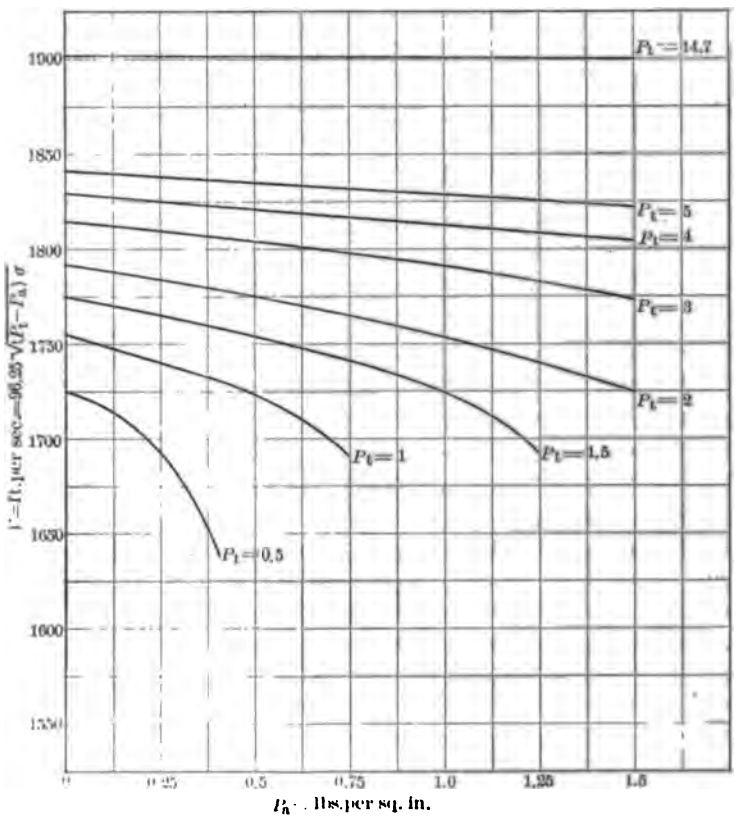


FIG. 11 VARIATION OF STEAM VELOCITY WITH AIR

hrough the exhaust pipe. This residual velocity in practice is sually from 200 to 600 ft. per sec. and in turbine installations may e as high as 800 ft. per sec. In direction, it follows the axis of he eduction nozzle until deflected by the tubes, sides of the con- enser or baffle plates, and constantly loses velocity until, at the urther end of the steam travel, this velocity is entirely lost. The

component of this residual velocity longitudinally to the tube is of no value in bringing a particle of steam to the condensing surface; neither is the component of this velocity normal to the tube surface, for its action is balanced by carrying away the steam on the opposite side of the tube. Its only action then is to distribute the steam among the tubes.

37 When a particle of steam comes in contact with the surface of the tube, it is immediately condensed and contracts enormously in volume. At atmospheric pressure the volume of water is approximately $\frac{1}{1660}$ of the steam volume. At 28 in. of vacuum, or 1 lb. abs., the volume is about $\frac{1}{21{,}500}$, and at 29., 5 in., or ½ lb. abs., 77,000 cu. ft. of steam condenses to 1 cu. ft. of water. The vacuum thus created induces a flow of steam normal to the steam surface, the velocity of which, neglecting friction, can easily be calculated for various conditions by means of the formula $V = \sqrt{2gh}$. Transforming this formula we get $V = 96.25 \sqrt{(P_t - P_a)\ \sigma}$, where P_t = vacuum pressure (lb. abs.), P_a = partial pressure due to air in the condenser, and σ = specific volume of steam at pressure $(P_t - P_a)$.

38 The velocity with which the steam particles strike the tube surface is apparently independent of the distance they travel before striking and is reasonably independent of the vacuum. The velocity varies from about 1750 ft. per sec. at 1 lb. abs. to about 1900 ft. per sec. at 14.7 lb. abs. or atmosphere. These values of V are shown in Fig. 11 and the effect of a small quantity of air in the condenser on the velocity of flow of the steam is shown to be very small.

THE EFFECT OF AIR UPON HEAT TRANSMISSION

39 During the early portion of these tests it was impossible even to approximate air-free steam, so that consistent transfer results could not be obtained. With the changing of the apparatus to a closed cycle, it was possible to keep the air down to a rather small quantity and the results obtained were much more consistent. It is probable in these cases that the partial air pressure never exceeded ½ in. and in most cases was below this point. By close attention to all possible sources of air leaks in the final tests run

m, say, No. 400 on, it is probable that the partial air pressure ver exceeded $\frac{1}{4}$ in. and was sometimes much less than this.

40 The best experiments on the effect of air that I have been e to find were described by James Alexander Smith in a paper read ore the Victorian Institute of Engineers on December 6, 1905, which s reprinted in London Engineering, March 23, 1906. An abstract this paper will be found in Appendix No. 2. His results show that partial pressure of air amounting to $\frac{1}{10}$ in. will reduce the heat nsmission 25 per cent; $\frac{1}{4}$ in. of air will reduce it 40 per cent; and $\frac{3}{8}$ partial air pressure will reduce the heat transfer about 50 per cent. is much to be regretted that Mr. Smith did not give his numbers, : the curves are sufficiently clear for use.

CONCLUSIONS

41 *a* The heat transferred from condensing steam surrounding a metallic tube to cold water flowing through the tube is proportional to the seven-eighths power of the mean temperature difference of the water and steam temperatures. This is equivalent to the statement that the coefficient of heat transfer, U, is inversely proportional to the eighth root of the mean temperature difference.

b The coefficient of heat transmission, U, is approximately proportional to the square root of the velocity of the cooling water.

c The coefficient U is independent of the vacuum and of the velocity of the steam among the tubes or in the condenser passages. It may be proportional to the square root of the velocity normal to the tubes, but in all common cases this velocity does not vary more than a tenth part.

d The effect of air on the heat transferred is very marked indeed, particularly at high vacua, and most of this air is due to leakage through the walls and joints of the apparatus. Working from Smith's curves and certain picked tests, where the volume of air could be calculated, the effect of the presence of air in reducing the value of U is as follows:

$$U = c\left(\frac{P_v}{P_s}\right)^5$$

0.55, Admiralty vulcanized inside, 0.47, glass, (ralty vulcanized both sides, 0.17. This coeffic the material of the tube) will be designated by sion, oxidation, vulcanizing, pitting, etc., l marked effect in reducing the transfer. This best shown by the Admiralty tube which gav may reduce the transfer at least 50 per cent

f The foregoing conclusions may be expressed cally as follows:

$$U = K \frac{C\rho^{\frac{1}{2}}\mu \sqrt{V_w}}{\theta^{\frac{1}{4}}}$$

where C = the cleanliness coefficient varying f 0.5

μ = the material coefficient varying fi 0.17

ρ = the steam richness ratio, $\frac{P_s}{P_t}$ varyi to 0

V_w = the water velocity in ft. per sec.

θ = the mean temperature difference

K = a constant, probably about 630

The effect of the length of tube, or rathe water travel, has not been considered and tl the condenser must be such that there is a passage to every tube.

g This expression for U is cumbersome to u

θ calculated on the geometrical curve is 18.2. For these cases it will be nearly as accurate and much simpler to calculate θ by the logarithmic method, neglecting θ in the denominator and using 435 or $\frac{630}{1.44}$ for K^1. The expression will then be $U = K^1 C P^{\frac{5}{6}} \mu \sqrt{V_w}$.

h The above equation agrees well with the results of a number of tests on full size condensers under varying conditions. There appears to have been no attempt to determine the amount of air handled by the air pump in these cases, but the amounts of air indicated by the formula are such as agree with the pressures and temperature taken. The measurement of the dry pump discharge has been undertaken and the author hopes to have more information on this point in the future.

? In conclusion, the author wishes to acknowledge the efficient rendered him in conducting the experiments and calculating the lts by his assistants, P. E. Reynolds and H. R. Callaway.

APPENDIX No. 1

LIST OF SYMBOLS USED AND TABLES RELATING TO TESTS MADE BY THE AUTHOR

V_w = water velocity, ft. per sec.
V_s = steam velocity, ft. per sec.
U = heat transmission coefficient, B.t.u. per sq. ft. per deg. difference per hr.
θ = temperature difference, deg. fahr.
θ_m = mean temperature difference, deg. fahr.
t_0 = temperature of inlet water
t_1 = temperature of overflow water
t = any temperature
t_s = temperature due to pressure of saturated steam
$\left.\begin{matrix} K \\ C \end{matrix}\right\}$ = constants
N = total heat transmitted per sq. ft. per hr., B.t.u.
h = head, ft.
g = 32.2
σ = specific volume of steam at pressure, $(P_t - P_a)$
P_t = vacuum pressure, lb. abs.
P_a = partial air pressure in condenser, lb. abs.
P_s = partial steam pressure in condenser, lb. abs.
μ = material coefficient
ρ = steam richness ratio, $\left(\frac{P_s}{P_t}\right)$
S = cooling surface, sq. ft.
Q = circulating water per hr., lb.
W = steam condensed per hr., lb.
$R = \frac{Q}{W}$
p = absolute pressure in condenser, in. of mercury

TABLE 3 TESTS OF HEAT TRANSFER THROUGH CONDENSER TUBES*

MADE WITH DRY VACUUM LINES ONLY SLIGHTLY OPEN

Test Number	Circulating Water Per Hour, Lb.	Steam Condensed Per Hour, Lb.	Ratio of Water to Steam, $\frac{Q}{W}$	Velocity of Water in Tube, Ft. Per Sec.	Absolute Pressure in Condenser, In. of Mercury	Temperature of Steam, Deg. Fahr.	Temperature of Inlet Water, Deg. Fahr.	Temperature of Outlet Water, Deg. Fahr.	Temperature Rise of Water, Deg. Fahr.	Mean Temperature Difference, Deg. Fahr.—Arith.	B.t.u. Per Sq. Ft. Per Hour per Deg. Mean Temperature Difference
	Q	W	R	V_w	p	t_s	t_0	t_1	$t_1 - t_0$	θ_m	U
Admiralty Tube, 1 in. Outside Diameter, 18 B.W.G.											
280	8510	53.2	160	8.43	2.67	110.5	36.04	42.52	6.48	71.22	774
281	8530	89.8	95	8.44	5.27	135.9	35.44	46.14	10.7	95.07	960
282	8670	134.2	64.5	8.56	9.82	160.9	35.36	51.04	15.68	117.7	1153
283	8660	166.2	52	8.55	15.09	178.8	36.5	55.5	19.0	132.8	1240
284	8550	211	40.5	8.44	32.0	215.5	37.3	61.2	23.9	166.3	1228
285	8570	157	54.7	8.47	14.99	178.4	36.07	54.20	18.13	133.2	1166
286	8550	125.5	68	8.44	9.99	161.4	37.73	52.58	14.85	116.2	1091
287	8625	83.5	103.3	8.53	4.95	132.1	38.30	48.15	9.85	88.9	955
288	8570	52.3	164	8.47	2.95	112.0	36.70	42.98	6.28	72.2	755
289	8570	180.0	47.7	8.47	22.82	197.9	39.15	59.63	20.48	148.5	1181
290	8550	178	48.1	8.44	22.92	198.2	37.75	58.05	20.3	150.3	1154
291	8625	55.2	156	8.53	2.79	116.2	35.8	42.38	6.58	77.09	737
292	8650	82.1	105	8.55	4.89	133.8	35.48	45.13	9.65	93.44	893
293	8570	124.2	69	8.47	9.90	161.6	35.43	50.10	14.68	118.9	1057
294	8625	152	57	8.53	14.90	178.8	36.40	53.73	17.43	133.8	1123
295	8525	174	49	8.42	22.52	197.6	36.38	56.38	20.00	151.3	1126
296	8750	55	159	8.64	3.06	117.6	37.53	43.98	6.45	76.8	734
297	8950	79.9	112	8.85	5.11	135.7	37.95	47.03	9.08	93.2	872
298	8900	120	74	8.80	9.91	161.4	37.00	50.65	13.65	117.5	1033
299	8825	149.5	59	8.72	14.98	179.2	36.45	53.20	16.75	134.4	1100
300	8825	174	50.7	8.72	22.56	198.0	36.93	56.23	19.30	151.4	1125
301	8875	120	73.8	8.77	9.86	161.3	36.65	50.33	13.68	117.8	1030
302	8370	59.7	140	8.27	3.28	118.8	37.3	44.6	7.3	77.85	785
303	8570	86.7	99	8.47	5.46	137.3	37.23	47.5	10.27	94.93	928
304	8525	125	68.2	8.42	10.63	164.3	36.1	50.73	14.63	120.9	1030
305	8525	148	57.7	8.42	15.53	180.4	36.17	53.32	17.15	135.7	1077
306	8475	167	50.6	8.37	23.13	198.8	36.92	56.27	19.35	152.2	1078
307	8420	65.2	129	8.32	4.26	129.3	36.63	44.53	7.9	88.7	751
308	8440	76.5	110.3	8.35	5.69	136.2	39.03	48.25	9.22	92.6	840
309	8600	112.5	76.3	8.50	10.15	160.7	39.08	52.35	13.27	115.0	991
310	8550	137	62.4	8.44	15.17	178.3	38.78	54.63	15.85	131.6	1030
311	8650	162	53.4	8.55	22.56	197.5	38.53	56.85	18.32	149.8	1058
312	8600	168	51.0	8.50	29.90	212.1	38.83	57.83	19.0	163.8	998
313	8925	54.5	164	8.82	3.04	115.6	39.33	45.6	6.27	73.1	765
315	8600	76.0	113.3	8.50	5.14	135.1	39.28	48.25	8.97	91.3	845
316	8600	109	78.7	8.50	10.02	161.3	39.0	51.83	12.83	115.9	952
317	8690	136	63.7	8.60	15.02	178.7	38.08	53.6	15.52	132.9	1015
318	8690	158	55.0	8.60	22.67	197.7	40.68	58.48	17.80	148.1	1043
319	8300	48.8	170	8.20	3.05	117.3	39.42	45.45	6.03	74.9	668
320	8300	74.5	111.5	8.20	5.03	135.0	38.4	47.5	9.1	92.05	821
321	8370	106	79.0	8.27	10.05	161.9	39.9	52.73	12.83	115.6	930

* Tests 220 to 336 inclusive made without removing tube from apparatus. When removed tube was found to be covered with an accumulation of the black paint which was used on gaskets and joints to stop air leakage.

TABLE 3 TESTS OF HEAT TRANSFER THROUGH CONDENSER TUBES—MADE WITH DRY VACUUM LINES ONLY SLIGHTLY OPEN

Test Number	Circulating Water Per Hour, Lb.	Steam Condensed Per Hour, Lb.	Ratio of Water to Steam, $\frac{Q}{W}$	Velocity of Water in Tube, Ft. Per Sec.	Absolute Pressure in Condenser, In. of Mercury	Temperature of Steam, Deg. Fahr.	Temperature of Inlet Water, Deg. Fahr.	Temperature of Outlet Water, Deg. Fahr.	Temperature Rise of Water, Deg. Fahr.	Mean Temperature Difference, Deg. Fahr.—Arith. B.t.u. Per Sq. Ft. Per
	Q	W	R	V_w	p	t_s	t_0	t_1	$t_1 - t_0$	θ_m
Admiralty Tube, 1 in. Outside Diameter, 18 B.W.G.										
322	8550	130	65.7	8.44	15.12	179.5	40.3	55.35	15.05	121.7
323	8440	151	55.9	8.35	22.65	197.5	38.15	55.65	17.5	150.6
324	8690	157	54.7	8.60	30.0	212.1	38.73	56.45	17.72	164.5
325	8750	172	50.8	8.64	34.06	218.8	38.83	57.83	19.0	170.5
326	8750	179	48.8	8.64	41.8	229.4	38.3	57.95	19.65	181.4
327	8650	191	45.2	8.55	60.9	250.2	37.98	58.88	20.9	202.1
328	8600	159	54.1	8.50	29.5	211.2	38.45	56.35	17.9	164.8
329	8650	166	51.9	8.55	35.5	220.9	39.02	57.6	18.58	172.6
330	8600	172	49.9	8.50	42.7	230.5	38.88	58.08	19.20	182.0
331	8550	187	45.6	8.44	61.4	250.4	40.2	60.88	20.68	199.9
332	9125	161	56.5	9.02	30.0	212.7	37.95	55.1	17.15	166.2
333	9025	174	51.7	8.92	35.6	221.6	38.0	56.65	18.65	174.0
334	8900	182	49.0	8.80	42.7	230.3	37.92	57.5	19.58	183.6
335	8850	197	44.9	8.75	61.5	251.5	38.55	59.6	21.05	202.4
336*	8300	104	80.0	8.20	9.9	161.8	37.5	50.13	12.63	118.0
337†	8700	118	73.5	8.60	9.9	161.5	38.18	51.95	13.77	116.4
338	8900	67.3	132	8.80	4.06	126.0	40.6	48.33	7.73	81.5
339	8840	78.7	111	8.74	5.02	133.8	40.1	49.3	9.20	89.1
340	8770	116	75.5	8.66	9.9	161.6	38.33	51.73	13.4	116.6
341	8770	138	63.7	8.66	14.6	179.1	38.7	54.23	15.53	133.6
342	8620	149	57.8	8.51	22.5	197.8	39.8	56.7	16.9	149.6
343	8650	133	64.8	8.55	22.5	197.6	39.4	54.48	15.08	150.7
344	8770	115	76.4	8.66	14.9	178.8	39.03	52.0	12.97	133.3
345	8650	94.0	92.0	8.55	9.9	160.9	38.85	49.83	10.98	116.6
346	8620	65.2	132	8.51	5.3	135.8	39.08	46.8	7.72	92.9
347	8890	69.5	128	8.77	3.01	115.5	41.83	49.83	8.00	98.7
New Admiralty Tube Installed, Tube Being Cleaned Every 8 or 10 Tests										
348	8700	91.3	95.2	8.59	5.02	133.8	40.58	51.25	10.67	87.9
349	8620	122	70.5	8.51	9.9	161.5	39.85	54.20	14.35	114.5
350	8700	160	54.3	8.59	14.8	178.7	37.73	55.93	18.2	131.9
351	8700	186	46.7	8.59	22.5	197.9	38.33	60.3	21.97	148.7
352	8470	67.7	125	8.36	3.00	115.3	39.45	47.65	8.20	71.7
353	8620	90.4	95.4	8.51	5.01	133.7	39.28	49.93	10.65	89.1
354	8470	120	70.4	8.36	9.90	160.1	37.93	52.23	14.35	114.9
355	8470	152	55.8	8.36	14.8	178.8	40.2	57.0	17.7	139.7
356	8540	188	45.5	8.44	22.5	197.6	44.98	66.48	21.5	141.8
357	8470	179	47.4	8.36	22.5	197.5	45.18	65.8	20.62	142.0
358	8540	149	57.3	8.44	14.8	178.5	42.85	60.10	17.25	137.0
359	8650	123	70.3	8.55	10.0	160.8	41.90	56.25	14.35	111.7
360	8650	87.7	98.7	8.55	5.02	133.7	41.55	51.85	10.30	87.0
361‡	8650	68.5	126	8.55	3.09	116.3	42.5	50.63	8.13	69.7
362	8810	90.8	97	8.70	5.11	135.1	42.58	53.05	10.47	87.3

* Test 336 made before cleaning tube.
† Test 337 made after cleaning tube.
‡ Tests 361 to 369 inclusive made with dry vacuum line wide open.

TABLE 3 TESTS OF HEAT TRANSFER THROUGH CONDENSER TUBES—Con.

MADE WITH DRY VACUUM LINES ONLY SLIGHTLY OPEN

Test Number	Circulating Water Per Hour, Lb.	Steam Condensed Per Hour, Lb.	Ratio of Water to Steam, $\frac{Q}{W}$	Velocity of Water in Tube, Ft. Per Sec.	Absolute Pressure in Condenser, In. of Mercury	Temperature of Steam, Deg. Fahr.	Temperature of Inlet Water, Deg. Fahr.	Temperature of Outlet Water, Deg. Fahr.	Temperature Rise of Water, Deg. Fahr.	Mean Temperature Difference, Deg. Fahr.—Arith.	B.t.u. Per Sq. Ft. Per Hour per Deg. Mean Temperature Difference
	Q	W	R	V_w	p	t_s	t_0	t_1	t_1-t_0	θ_m	U
New Admiralty Tube Installed, Tube Being Cleaned Every 8 or 10 Tests											
363	8650	129	67	8.55	10.09	161.7	41.58	56.5	14.92	112.7	1145
364	8650	162	53.6	8.55	15.19	179.6	38.58	57.03	18.45	131.8	1210
365	8620	195	44.3	8.51	22.79	198.2	40.8	62.9	22.1	146.4	1297
366	8810	222	39.7	8.70	22.77	198.1	42.0	66.63	24.63	143.8	1505
367	8770	169	52	8.66	15.07	178.9	41.68	60.7	19.02	127.7	1307
368	8770	135	65.1	8.66	10.09	161.9	45.4	60.78	15.38	108.8	1237
369	8810	94.2	93.6	8.70	5.09	134.6	45.48	56.33	10.85	83.7	1142
370	8770	69.0	127	8.66	3.11	117.0	44.68	52.73	8.05	68.3	1032
371	8500	44.7	190	8.40	2.28	105.4	46.35	51.8	5.45	56.3	822
372	8440	57.3	147	8.32	3.15	116.3	42.03	49.03	7.00	70.8	832
373	8540	69.3	123	8.44	5.22	136.1	45.2	53.45	8.25	86.8	812
374	8390	91.3	91.8	8.29	10.2	162.2	45.9	56.8	10.9	110.9	825
Admiralty Tube, 1 in. Outside Diameter, 18 B.W.G.											
375	8620	111	77.5	8.51	15.22	179.5	44.53	57.28	12.75	128.6	847
376	8500	126	67.3	8.40	23.0	198.5	46.05	60.6	14.55	145.2	852
378	8280	51.6	160	8.17	2.63	110.7	49.03	55.48	6.45	58.4	912
379	8470	74.2	114	8.36	5.00	132.8	48.58	57.48	8.90	79.8	942
380	8570	106	81	8.47	9.78	160.1	43.80	56.28	12.48	110.1	973
381	8540	125	68	8.44	14.78	178.4	44.60	59.15	14.55	126.5	982
382	8540	161	53	8.44	22.33	196.9	43.62	62.13	18.50	144.0	1098
383	8620	122	70.4	8.51	9.58	159.6	44.25	58.60	14.35	108.2	1142
384	9150	63	145	9.03	2.80	114.1	47.8	54.90	7.1	62.7	1035
385	9040	75.2	120	8.92	3.85	125.4	48.5	56.98	8.48	72.7	1055
386	9120	62.8	145	9.00	2.80	113.8	47.55	54.63	7.08	62.7	1030
387	8840	75.5	117	8.74	3.82	124.8	46.53	55.13	8.7	74.0	1040
388	8960	63.0	142	8.85	2.80	113.6	45.5	52.7	7.2	64.5	1000
389	8730	74.0	118	8.62	3.82	124.7	46.65	55.33	8.68	73.7	1030
390	8925	85.8	104	8.81	4.77	133.5	46.5	56.28	9.78	82.1	1063
391	8925	49.5	180	8.81	2.07	103.9	52.3	58.03	5.73	48.7	1052
392	9000	64.7	139	8.89	2.93	115.0	47.88	55.25	7.37	63.4	1045
393	9040	81.4	111	8.92	4.90	133.0	45.18	54.3	9.12	83.3	990
394	8840	81.8	107	8.74	4.93	133.1	52.98	62.45	9.47	75.4	1110
395	9000	123	73.3	8.89	9.91	161.0	52.4	66.18	13.78	101.7	1220
396	8925	149	59.7	8.81	14.96	179.0	51.42	68.1	16.68	119.2	1248
Copper Tube, 1 in. Outside Diameter, 16 B.W.G.											
397	8730	53.5	163	8.65	2.98	115.6	46.98	53.28	6.30	65.5	840
398	8840	71.2	124	8.77	4.95	133.6	46.95	55.18	8.23	82.5	872
399	8890	70.5	126	8.80	4.95	133.3	42.73	50.83	8.10	86.5	832
400	8770	91.2	96.2	8.70	9.9	161.0	45.25	55.75	10.5	111.5	827
401	9000	57.3	157	8.92	3.26	118.1	48.6	55.13	6.53	66.2	888
402	8810	81.5	108	8.73	5.23	135.5	46.32	56.75	9.43	84.0	990
403	8890	119	75.0	8.80	10.23	162.1	48.85	62.2	13.35	106.6	1110
404	8970	134	67.0	8.83	15.26	179.8	45.8	60.53	14.73	126.6	1060
405	8925	152	58.8	8.80	22.97	198.3	49.1	65.75	16.65	140.9	1053

TABLE 3 TESTS OF HEAT TRANSFER THROUGH CONDENSER TUBES—Con.
MADE WITH DRY VACUUM LINES ONLY SLIGHTLY OPEN

Test Number	Circulating Water Per Hour, Lb.	Steam Condensed Per Hour, Lb.	Ratio of Water to Steam, $R = \frac{Q}{W}$	Velocity of Water in Tube, Ft. Per Sec.	Absolute Pressure in Condenser, In. of Mercury	Temperature of Steam, Deg. Fahr.	Temperature of Inlet Water, Deg. Fahr.	Temperature of Outlet Water, Deg. Fahr.	Temperature Rise of Water, Deg. Fahr.	Mean Temperature Difference, Deg. Fahr.—Arith.	B.t.u. Per Sq. Ft. Per Hour per Deg. Mean Temperature Difference
	Q	W	R	V_w	p	t_s	t_0	t_1	$t_1 - t_0$	θ_m	U
Copper Tube, 1 in. Outside Diameter, 16 B.W.G.											
406	9040	134	67.3	8.92	15.2	179.5	46.45	61.15	14.7	125.7	1057
407	8810	114	77.3	8.70	10.15	162.0	44.75	57.7	12.95	110.8	1030
408	8925	83.5	107	8.81	5.2	135.0	45.55	55.08	9.53	84.7	1005
409	8810	63.4	139	8.70	3.2	117.5	49.18	56.53	7.35	64.6	1003
Aluminum Bronze Tube, 1 in. Outside Diameter, 18 B.W.G.											
410	8650	66.5	130	8.55	3.29	118.1	44.68	52.58	7.90	69.5	984
411	9040	83.5	108	8.92	5.17	135.1	49.38	58.8	9.42	81.0	1047
412	8970	108	83.2	8.85	10.22	162.0	48.50	60.53	12.03	107.5	1002
413	8925	119	75.0	8.81	15.19	179.2	44.1	57.3	13.2	128.5	918
414	8925	138	64.7	8.81	22.85	198.0	44.58	59.83	15.25	145.8	932
415	9000	142	63.5	8.89	22.87	198.1	43.48	58.80	15.42	147.0	943
416	8810	115	76.6	8.70	15.17	179.3	45.68	58.60	12.92	127.2	895
417	8770	108	81.5	8.66	10.14	161.7	47.28	59.68	12.4	108.2	1005
418	8770	76.2	115	8.66	5.09	135.4	47.63	56.43	8.80	83.4	925
419	8810	63.8	138	8.70	3.14	116.6	40.2	47.63	7.43	72.7	900
Copper Tube. 1 in. Outside Diameter, 16 B.W.G.											
420	8890	61.2	145	8.80	3.13	116.5	42.35	49.45	7.1	70.6	893
421	8700	78.4	111	8.60	5.08	134.1	42.35	51.55	9.20	87.1	918
422	8650	108	79.8	8.98	10.18	162.0	41.78	54.30	12.52	114.0	950
423	8730	127	68.5	9.05	15.07	178.9	41.90	56.33	14.43	139.7	973
424	8650	146	59.0	8.98	22.83	197.9	42.63	59.23	16.60	147.0	977
Cupro-Nickel, 1 in. Outside Diameter, 18 B.W.G.											
425	8840	57.3	154	8.74	3.09	116.0	42.48	49.15	6.67	69.2	853
426	9120	74	123	9.00	4.87	132.9	42.45	50.73	8.28	80.3	875
427	9120	101	90.6	9.00	9.81	160.6	42.00	53.15	11.15	113.0	898
428	8890	120	74	8.77	14.87	178.7	41.13	54.48	13.35	130.9	907
429	9080	145	62.6	8.96	22.56	197.4	40.63	56.28	15.65	148.9	953
431	8970	57.5	156	8.85	3.04	115.8	40.38	46.95	6.58	72.1	820
432	8840	72.4	122	8.74	4.94	133.6	41.35	49.7	8.35	88.1	838
433	8840	98.7	89.7	8.74	10.03	161.1	41.68	52.93	11.25	113.8	875
434	9000	117	76.8	8.89	14.98	178.9	43.6	61.48	12.88	123.9	935
435	8810	139	63.3	8.70	22.89	198.0	46.35	61.83	15.48	143.9	948
Aluminum-Lined Copper Tube, 1 in. Outside Diameter, 0.06 in. Thick											
436	8840	61.7	143	9.18	3.07	115.1	43.08	50.23	7.15	68.9	918
437	8925	82.6	108	9.25	5.07	133.9	42.2	51.63	9.43	87.0	967
438	9000	116	77.7	9.34	10.13	161.7	42.18	55.18	13.0	113.0	1033
439	9080	137	66.2	9.41	15.1	178.8	42.98	57.93	14.95	128.3	1058
440	9040	162	55.8	9.36	22.95	198.1	42.58	60.1	17.52	146.8	1078
441	8970	168	53.4	9.30	22.95	198.1	41.5	59.82	18.32	147.4	1110
442	9040	144	62.7	9.36	15.05	178.1	40.88	56.65	15.77	129.3	1098
443	8970	120	74.7	9.30	10.02	162.4	41.98	55.38	13.4	113.7	1055
444	9040	82.8	109	9.36	4.96	133.3	42.30	51.63	9.33	86.3	975
445	8890	59.7	149	9.21	3.09	115.9	42.05	48.95	6.90	70.4	887

ABLE 3 TESTS OF HEAT TRANSFER THROUGH CONDENSER TUBES—Con.

MADE WITH DRY VACUUM LINES ONLY SLIGHTLY OPEN

	Circulating Water Per Hour, Lb.	Steam Condensed Per Hour, Lb.	Ratio of Water to Steam, $\frac{Q}{W}$	Velocity of Water in Tube, Ft. Per Sec.	Absolute Pressure in Condenser, In. of Mercury	Temperature of Steam, Deg. Fahr.	Temperature of Inlet Water, Deg. Fahr.	Temperature of Outlet Water, Deg. Fahr.	Temperature Rise of Water, Deg. Fahr.	Mean Temperature Difference, Deg. Fahr.—Arith.	B.t.u. Per Sq. Ft. Per Hour per Deg. Mean Temperature Difference
	Q	W	R	V_w	p	t_s	t_0	t_1	$t_1 - t_0$	θ_m	U
Monel Tube, 1 in. Outside Diameter, 18 B.W.G.											
	8925	57.1	156	8.81	3.51	119.6	40.58	47.13	6.55	75.7	773
	8810	68.2	129	8.70	5.01	133.3	40.80	48.68	7.88	88.6	783
	8970	91.0	98.5	8.85	10.08	161.5	40.80	51.03	10.23	115.6	794
	8840	107	82.5	8.74	14.96	178.5	40.50	52.5	12.0	132.0	805
	8970	128	70.0	8.85	22.98	198.1	40.15	54.13	13.98	151.0	830
	8810	126	70.0	8.70	23.01	198.1	40.0	54.0	14.0	151.1	817
	9000	107	83.8	8.89	15.01	178.1	40.8	52.6	11.8	131.4	807
	8890	89	100	8.77	9.95	160.5	41.13	51.2	10.07	114.3	792
	8890	66.3	134	8.77	5.00	133.1	41.55	49.13	7.58	87.8	768
	9040	55.4	163	8.92	3.42	118.8	40.95	47.25	6.30	74.7	762
Admiralty Tube, Oxidized, 1 in. Outside Diameter, 18 B.W.G.											
	8840	129	68.7	8.74	15.04	178.9	44.98	59.38	14.4	126.7	1005
	8840	151	58.5	8.74	22.94	198.2	45.25	61.98	16.73	144.6	1023
	8810	149	59.0	8.70	22.95	198.5	43.98	60.55	16.57	146.2	998
	9080	127	71.5	8.96	15.05	178.8	43.8	57.63	13.83	128.1	980
	9040	103	88.0	8.92	10.02	161.4	46.33	57.8	11.48	109.3	958
	8970	74.7	12.0	8.85	5.05	134.2	48.38	56.88	8.50	81.6	934
	8890	63.0	141	8.77	3.67	123.2	47.13	54.38	7.25	72.9	885
	9040	78.5	115	8.92	5.37	136.0	47.03	55.9	8.87	84.5	948
	8810	108	81.3	8.70	10.39	162.6	45.55	57.85	12.3	110.9	977
Zinc Tube, 1 in. Outside Diameter, 18 B.W.G.											
	9000	53.0	170	8.89	3.52	120.4	44.85	50.88	6.03	72.5	738
	8925	65.0	137	8.81	5.49	137.1	44.1	51.5	7.40	89.3	740
	8970	84.6	106	8.85	10.34	162.6	45.12	54.58	9.45	112.8	751
	8840	100	88	8.74	15.32	179.8	44.15	55.4	11.25	130.0	765
	8970	121	74	8.85	23.38	199.5	43.55	56.78	13.23	149.3	793
	8925	46.2	193	8.81	3.36	118.8	49.5	54.8	5.30	66.7	712
	8925	63.2	141	8.81	5.35	136.5	43.62	50.82	7.20	89.3	720
	9080	82.5	110	8.96	10.35	162.4	46.33	55.45	9.12	111.5	740
	9040	96.0	94.3	8.92	15.20	179.5	49.00	59.5	10.5	125.2	757
	9040	115	78.3	8.92	23.07	198.5	49.10	61.6	12.5	143.1	787
Aluminum-Bronze Tube, 1 in. Outside Diameter, 18 B.W.G.											
	8925	62.3	143	8.81	3.53	120.7	42.85	50.02	7.17	74.3	852
	8925	75.6	118	8.81	5.38	136.6	42.4	51.02	8.62	89.9	857
	8730	95.2	91.8	8.62	10.28	162.5	45.72	56.8	11.08	111.2	870
	8890	112	79.5	8.77	15.28	179.9	52.28	64.73	12.45	121.4	910
	9000	133	67.3	8.89	23.19	198.2	47.98	62.5	14.52	142.9	915
	8840	65.0	136	8.74	4.03	126.5	45.10	52.82	7.52	77.6	857
	9040	73.5	123	8.92	5.08	134.8	43.85	52.13	8.28	86.8	860
	8730	95.0	92.0	8.62	9.95	160.75	44.55	55.55	11.0	110.7	868
	8970	117	76.2	8.85	15.13	179.1	48.02	61.00	12.98	124.6	938
	8890	133	67.1	8.77	23.03	198.5	49.32	64.12	14.8	141.8	927
	9000	95.0	94.8	8.89	10.15	161.6	51.3	61.95	10.65	105.0	912

TABLE 3 TESTS OF HEAT TRANSFER THROUGH CONDENSER TUBES—Con.

MADE WITH DRY VACUUM LINES ONLY SLIGHTLY OPEN

Test Number	Circulating Water Per Hour, Lb.	Steam Condensed Per Hour, Lb.	Ratio of Water to Steam, $\frac{Q}{W}$	Velocity of Water in Tube, Ft. Per Sec.	Absolute Pressure in Condenser, In. of Mercury	Temperature of Steam, Deg. Fahr.	Temperature of Inlet Water, Deg. Fahr.	Temperature of Outlet Water, Deg. Fahr.	Temperature Rise of Water, Deg. Fahr.	Mean Temperature Difference, Deg. Fahr.—Arith.	B.t.u. Per Sq. Ft. Per Hour per Deg. Mean Temperature Difference
	Q	W	R	V_w	p	t_s	t_0	t_1	t_1-t_0	θ_m	U
Admiralty Tube, Lead Lined, 1 in. Outside Diameter, 0.088 in. Thick											
491	9000	55.2	163	10.54	4.02	125.6	49.98	56.25	6.27	72.5	778
492	8890	62.6	142	10.50	5.12	134.5	50.68	57.85	7.17	80.2	795
493	8770	87.7	100	10.36	10.01	161.1	51.35	61.4	10.05	104.7	845
494	8840	108	81.5	10.45	14.99	179.0	50.23	62.4	12.17	122.7	875
495	8810	129	68.3	10.41	22.84	198.0	49.73	64.08	14.35	141.1	895
496	8840	130	68.1	10.46	22.77	198.1	47.7	62.08	14.38	143.2	887
497	8650	110	78.5	10.23	14.94	178.9	45.63	58.25	12.62	127.0	860
498	8620	92.8	93.0	10.18	9.99	161.0	44.68	55.55	10.87	110.9	852
499	8620	69.0	125	10.18	5.86	139.1	44.9	52.98	8.08	90.1	773
Shelby Steel Tube, 1 in. Outside Diameter, 18 B.W.G.											
500	8970	55.0	163	8.85	3.49	120.0	45.88	52.15	6.27	71.0	788
501	8925	65.0	137	8.81	5.01	132.9	45.38	52.8	7.42	83.8	790
502	8840	82.6	107	8.74	10.03	161.1	46.35	55.83	9.47	110.0	762
503	8970	99.5	90.2	8.85	15.0	179.0	45.93	56.9	10.97	127.6	775
504	8970	111	80.5	8.85	22.80	198.1	49.88	62.03	12.15	142.1	765
505	8970	108	83.2	8.85	22.77	198.1	55.28	67.05	11.77	136.9	770
506	9040	94.5	95.7	8.92	14.89	178.4	51.95	62.28	10.33	121.3	770
Shelby Steel Tube with Coating of Rust											
507	8925	44.8	199	8.81	3.53	121.1	52.65	57.8	5.15	65.9	695
508	8840	55.5	159	8.74	5.23	135.3	49.3	55.68	6.38	82.8	682
509	8730	71.0	123	8.62	10.26	162.5	44.63	52.78	8.15	112.8	630
Tin Tube, 1 in. Outside Diameter, 0.055 in. Thick											
510	8840	47.2	187	9.12	3.59	120.8	57.25	62.73	5.48	60.8	797
511	8650	64.0	135	8.92	5.09	133.8	44.9	52.4	7.50	85.1	764
512	8890	87.0	102	9.15	10.17	161.4	44.4	54.2	9.80	112.1	778
513	8770	96.3	91.2	9.04	15.14	179.0	52.33	63.18	10.85	121.2	785
514	8570	113	75.5	8.84	23.17	198.6	51.7	64.53	12.83	140.5	783
515	8650	113	76.6	8.92	22.94	198.4	51.23	63.88	12.65	140.8	778
516	8970	96.6	93.0	9.24	15.12	178.8	52.7	63.35	10.65	120.8	790
517	8840	81.0	109	9.12	10.10	161.0	52.88	62.18	9.30	103.4	793
518	8700	60.8	143	8.98	5.10	133.5	50.95	58.05	7.10	79.0	781
519	8890	53.5	166	9.15	4.10	125.6	51.93	58.10	6.17	70.6	775
Old Admiralty Tube Taken from Large Condenser, 1 in. Outside Diameter, 18 B.W.G.											
520	8730	48.2	181	8.62	4.49	129.0	45.0	50.63	5.63	81.2	606
521	8620	69.0	125	8.51	9.87	159.8	53.2	61.28	8.08	102.6	675
522	8620	84.5	102	8.51	14.87	177.9	52.58	62.25	9.67	121.4	686
523	8650	103	84	8.55	22.87	197.9	50.23	61.88	11.65	141.8	710
524	8650	105	82.5	8.55	22.77	197.1	46.48	58.35	11.87	144.6	710
525	8730	43.0	203	8.62	3.51	121.1	52.68	57.73	5.05	65.9	667
526	8700	53.2	163	8.58	5.23	135.4	53.23	59.45	6.22	79.1	683
527	8840	73.0	121	8.74	10.28	162.3	54.2	62.5	8.30	103.9	704
528	8840	86.6	102	8.74	15.20	179.3	55.03	64.75	9.72	119.4	717

TABLE 4 TESTS OF HEAT TRANSFER THROUGH CONDENSER TUBES

MADE TO DETERMINE EFFECT OF CIRCULATING WATER VELOCITY ON HEAT TRANSFER

Test Number	Circulating Water Per Hour, Lb.	Steam Condensed Per Hour, Lb.	Ratio of Water to Steam, $\frac{Q}{W}$	Velocity of Water in Tube, Ft. Per Sec.	Absolute Pressure in Condenser, In. of Mercury	Temperature of Steam, Deg. Fahr.	Temperature of Inlet Water, Deg. Fahr.	Temperature of Outlet Water, Deg. Fahr.	Temperature Rise of Water, Deg. Fahr.	Mean Temperature Difference, Deg. Fahr.—Arith.	B.t.u. Per Sq. Ft. Per Hour Per Deg. Mean Temperature Difference
	Q	W	R	V_w	p	t_s	t_0	t_1	t_1-t_0	θ_m	U
Old Admiralty Tube Taken from Large Condenser, 1 in. Outside Diameter, 18 B.W.G.											
529	11252	53.8	209	11.3	5.25	134.4	50.6	55.48	4.88	82.4	668
530	10530	51.6	204	10.4	5.28	135.5	49.75	54.75	5.00	88.2	634
531	9340	49.1	190	9.24	5.23	134.3	49.6	54.98	5.38	81.8	615
532	8240	47.3	174	8.15	5.23	134.1	50.05	55.93	5.88	81.1	595
533	6490	42.5	152	6.42	5.20	133.8	50.3	57.03	6.73	80.1	545
534	6030	42.7	141	5.97	5.25	134.1	52.3	59.55	7.25	78.2	558
535	4440	37.0	120	4 49	5.23	133.8	48.05	56.58	8.53	81.0	473
536	3640	33.0	110	3.60	5.25	133.9	50.23	59.53	9.3	79.0	428
537	1670	21.4	78	1.65	5.23	134.0	50.25	63.33	13.08	77.2	283
538	1440	19.7	73.1	1.43	5.13	134.8	52.5	66.45	13.95	75.3	267
539	2425	27.1	89.7	2.41	5.02	134.3	51.88	63.25	11.38	76.7	360
540	2737	28.2	97.0	2.72	5.12	134.4	54.43	64.95	10.52	74.7	388
541	3640	33.1	110	3.60	5.10	134.8	55.43	64.7	9.28	74.7	453
542	5085	39.1	130	5.03	5.04	134.3	54.48	62.35	7.87	75.9	537
543	6255	45.0	139	6.19	5.14	134.6	51.35	58.7	7.35	79.6	578
544	7855	47.8	164	7.77	5.10	134.3	54.1	60.33	6.23	77.1	635
545	8425	50.1	168	8.33	5.10	134.8	50.7	56.78	6.08	81.1	633
546	10000	53.8	186	9.91	5.02	134.3	49.48	54.98	5.50	83.1	670
547	11495	57.2	201	11.4	5.07	134.1	50.0	55.08	5.08	81.6	716
Admiralty Tube, 1 in. Outside Diameter, 18 B.W.G.											
548	11325	69.8	162	11.2	4.06	126.3	50.9	57.25	6.35	72.2	1000
549	9980	67.4	148	9.88	4.11	126.3	51.38	58.3	6.91	71.5	967
550	9560	66.3	144	9.47	4.08	126.1	50.7	57.8	7.10	71.8	945
551	9225	65.8	140	9.13	4.06	126.3	50.5	57.83	7.33	72.1	938
552	7700	58.3	132	7.62	4.11	126.6	53.55	61.3	7.75	69.2	864
553	6525	54.8	119	6.46	4.11	126.4	50.58	59.2	8.62	71.5	788
554	5500	50.0	110	5.44	4.11	127.0	51.43	60.73	9.30	70.9	722
555	4060	42.2	96.4	4.02	4.13	127.1	51.90	62.55	10.65	69.9	618
556	2693	31.7	85.0	2.66	4.13	126.6	54.73	66.78	12.05	65.8	492
557	1212	17.5	69.5	1.20	4.13	127.0	53.88	68.63	14.75	65.7	273
558	11515	67.3	156	11.4	3.95	124.9	50.98	57.58	6.60	70.6	1076
559	10160	69.0	147	10.1	4.10	126.1	52.05	59.05	7.00	70.5	1006
560	7700	62.1	124	7.63	4.08	126.3	53.03	61.28	8.25	69.1	920
561	9260	64.7	143	9.17	4.03	125.4	56.5	63.68	7.18	65.8	1005
562	6830	59.8	114	6.76	4.00	125.1	49.08	58.1	9.02	71.5	862
563	5120	52.4	97.8	5.07	4.08	126.4	47.53	58.03	10.50	73.6	732
564	3980	42.0	94.7	3.94	4.13	126.7	53.9	64.73	10.83	67.4	640
565	2675	32.7	81.8	2.65	4.15	126.8	54.3	66.85	12.55	66.2	507
566	1250	18.1	69.1	1.24	4.15	127.0	53.98	68.83	14.85	65.6	283
567	11380	74.2	153	11.26	4.12	126.5	49.58	56.30	6.72	73.6	1040
568	9795	69.0	142	9.70	4.02	125.4	50.25	57.48	7.23	71.5	950
569	9225	65.3	141	9.12	4.02	125.0	50.38	57.68	7.30	71.0	947
570	7400	61.7	120	7.32	4.12	126.0	50.43	58.95	8.52	70.3	896
571	6340	59.2	107	6.27	4.11	126.5	49.83	59.38	9.55	71.9	842
572	4332	52.5	82.4	4 28	4.16	126.9	49.80	62.25	12.45	70.9	760
573	4475	52.5	85 2	4.43	4.11	126.0	49.8	61.83	12.03	70.2	769
574	11520	78.3	147	11.40	4.28	127.5	53.78	59.78	7.00	71.2	1122

TABLE 4 TESTS OF HEAT TRANSFER THROUGH CONDENSER TUBES—

MADE TO DETERMINE EFFECT OF CIRCULATING WATER VELOCITY ON HEAT TRANSFE

Test Number	Circulating Water Per Hour, Lb.	Steam Condensed Per Hour, Lb.	Ratio of Water to Steam, $\frac{Q}{W}$	Velocity of Water in Tube, Ft. Per Sec.	Absolute Pressure in Condenser, In. of Mercury.	Temperature of Steam, Deg. Fahr.	Temperature of Inlet Water, Deg. Fahr.	Temperature of Outlet Water, Deg. Fahr.	Temperature Rise of Water, Deg. Fahr.	Mean Temperature Difference Deg. Fahr.—Arith.
	Q	W	R	V_w	p	t_s	t_0	t_1	t_1-t_0	θ_m
Admiralty Tube, 1 In. Outside Diameter, 18 B.W.G.										
575	9750	72.7	134	9.65	4.18	126.4	53.63	61.28	7.65	68.8
576	8770	68.1	130	8.67	4.10	125.6	50.35	58.33	7.98	71.3
577	8620	66.6	130	8.52	4.20	126.4	51.7	59.63	7.93	70.7
578	7055	59.9	118	6.98	4.13	126.0	52.25	60.95	8.70	69.4
579	4060	43.3	93.6	4.01	4.13	126.1	51.45	62.4	10.95	68.7
580	5885	55.2	107	5.82	4.08	125.5	49.15	58.78	9.63	71.5
581	2690	32.9	81.7	2.67	4.23	126.6	49.68	62.25	12.57	69.6
582	872	12.9	67.7	0.86	4.26	127.4	51.85	67.03	15.18	68.9
583	11270	79.4	142	11.3	4.10	125.5	47.25	54.48	7.23	74.6
584	11340	78.0	146	11.4	4.00	125.9	50.45	57.5	7.05	71.9
585	9905	73.1	135	9.8	4.03	126.0	50.45	58.03	7.58	71.8
586	8425	67.1	125	8.33	4.00	125.3	50.5	58.68	8.18	70.7
587	8390	67.6	124	8.30	3.97	124.8	47.13	55.4	8.27	73.5
588	6680	61.1	109	6.61	4.05	126.5	48.1	57.5	9.40	73.7
589	4060	44.1	92	4.01	4.07	126.0	50.63	61.8	11.17	69.8
590	5195	49.1	106	5.14	3.93	124.5	51.7	61.4	9.70	66.9
591	2767	32.6	84.8	2.74	4.10	126.6	53.15	65.25	12.10	67.4
592	2463	30.7	80.3	2.44	4.20	128.1	54.6	67.38	12.78	67.1
593	1743	22.9	76.2	1.65	4.12	126.5	55.68	69.15	13.47	64.1
594	986	13.8	71.5	0.98	4.15	126.3	57.25	71.6	14.35	61.9
595	11340	72.1	157	11.4	4.09	126.6	47.6	54.12	6.53	75.7
596	9985	68.0	147	9.88	4.09	126.8	47.7	54.68	6.98	75.6
597	8460	61.8	137	8.37	3.97	125.1	47.02	54.5	7.48	74.3
598	7665	59.2	129	7.59	4.12	127.1	48.55	56.48	7.93	74.6
599	6520	52.9	123	6.46	3.99	125.5	49.3	57.65	8.35	72.0
600	4890	45.7	107	4.84	4.07	126.4	49.48	59.08	9.60	72.1
601	8035	89.5	90.0	3.00	4.09	126.5	51.1	62.55	11.45	69.6
602	3375	35.2	96.0	3.34	3.99	125.1	51.82	62.52	10.7	67.9
603	1972	24.5	80.5	1.95	4.07	126.6	51.82	64.65	12.83	68.3
604	949	13.9	68.0	0.94	4.15	127.0	50.6	65.7	15.1	66.8
605	11075	139	79.5	10.95	18.0	187.0	47.06	59.45	12.37	133.7
606	9835	133	73.9	9.74	17.98	186.8	46.68	59.98	13.3	133.5
607	8615	127	68.0	8.52	17.95	186.8	46.72	61.18	14.46	132.9
608	7895	121	65.4	7.82	18.05	187.1	46.8	61.83	15.03	133.8
609	5960	107	55.6	5.89	17.97	186.8	46.95	64.63	17.68	131.0
610	3830	82.6	46.4	3.79	17.92	186.7	47.38	68.58	21.2	128.7
611	2010	52.4	38.4	1.99	18.05	187.0	47.98	73.56	25.57	126.2
612	2313	59.8	38.7	2.29	18.0	186.8	48.0	73.38	25.38	126.1
613	873	25.3	34.5	0.86	17.95	187.0	49.10	77.53	28.43	122.7
614	11380	135	84.3	11.28	17.82	186.4	47.68	59.32	11.66	132.9
615	9985	127	78.6	9.87	17.99	186.9	48.18	60.68	12.5	132.5
616	8730	120	73.0	8.64	17.99	186.6	48.50	61.95	13.45	131.4
617	7855	115	68.4	7.77	17.82	186.0	48.25	62.62	14.38	130.6
618	6605	105	63.2	6.53	17.89	186.8	49.55	65.10	15.55	128.9
619	4970	88.8	56.0	4.92	17.97	186.6	48.10	65.98	17.88	129.7
620	3412	71.6	47.6	3.38	18.01	186.6	48.05	68.7	20.65	129.2
621	1479	39.6	37.4	1.46	18.19	187.3	48.70	75.08	26.38	126.6
622	2463	58.4	42.2	2.44	17.99	186.6	48.18	71.43	23.25	129.3

TABLE 5 TESTS OF HEAT TRANSFER THROUGH CONDENSER TUBES

MADE TO DETERMINE EFFECT OF VARIATIONS OF MEAN TEMPERATURE DIFFERENCE ON HEAT TRANSFER

Test Number	Circulating Water Per Hour, Lb.	Steam Condensed Per Hour, Lb.	Ratio of Water to Steam, $\frac{Q}{W}$	Velocity of Water in Tube, Ft. Per Sec.	Absolute Pressure in Condenser, In. of Mercury	Temperature of Steam, Deg. Fahr.	Temperature of Inlet Water, Deg. Fahr.	Temperature of Outlet Water, Deg. Fahr.	Temperature Rise of Water, Deg. Fahr.	Mean [Temperature Difference, Deg. Fahr.—Artifi.	B.t.u. Per Sq. Ft. Per Hour Per Deg. Mean Temperature Difference
	Q	W	R	V_w	p	t_s	t_0	t_1	$t_1 - t_0$	θ_m	U
Admiralty Tube, 1 in. Outside Diameter, 18 B.W.G.											
633	9000	59.2	153	8.91	2.65	111.6	46.98	53.35	6.37	60.9	940
634	9040	54.6	165	8.94	2.70	111.5	47.53	53.8	6.27	60.3	990
635	8840	44.3	199	8.75	2.70	111.3	61.05	66.25	5.20	47.9	967
636	8840	37.5	236	8.75	2.65	111.0	69.95	74.35	4.40	38.6	1000
637	8970	30.3	296	8.86	2.73	111.9	81.35	85.35	3.50	30.3	1106
638	9040	14.3	593	8.94	2.75	112.1	96.53	100.28	1.75	12.7	1283
638	8890	56.4	157	8.79	2.90	114.6	47.90	54.48	6.58	63.4	990
639	8840	44.4	199	8.75	2.90	114.1	63.53	68.03	5.20	48.7	945
640	8890	40.0	222	8.79	2.93	114.3	70.08	74.78	4.70	41.9	990
641	8970	34.4	261	8.86	2.93	115.1	79.58	83.55	3.97	33.5	1062
642	8810	24.8	354	8.72	2.95	114.4	90.13	96.10	2.92	22.6	1127
643	8810	17.0	518	8.72	2.95	116.0	99.4	101.4	2.00	15.6	1120
644	8620	8.50	1015	8.53	2.95	114.5	107.16	108.18	1.02	8.00	1260
645	8810	14.7	599	8.72	2.87	113.9	99.72	101.45	1.73	13.3	1145
646	8810	23.0	384	8.72	2.87	113.9	90.35	96.55	2.70	21.7	1095
647	8730	30.6	285	8.63	2.90	114.4	83.60	86.23	2.63	20.0	1055
648	8730	39.4	222	8.63	2.85	113.5	69.85	74.55	4.67	41.3	995
649	9000	57.1	158	8.91	3.00	115.4	48.56	55.13	6.57	63.5	930
650	9000	50.2	179	8.91	3.05	116.0	59.8	65.58	5.78	53.3	975
651	9000	41.0	220	8.91	2.97	114.5	70.53	75.25	4.72	41.6	1018
652	8925	32.1	278	8.83	3.00	114.6	81.35	85.08	3.73	31.4	1060
653	8810	25.0	353	8.72	3.03	115.1	90.00	92.83	2.83	23.7	1068
654	8925	17.2	518	8.83	3.05	117.4	100.96	102.96	2.00	15.4	1158
655	8890	4.30	2070	8.79	3.04	115.5	111.68	112.38	0.50	3.30	1342
656	8925	4.40	2030	8.83	3.04	115.0	111.13	111.64	0.51	3.60	1363
657	8925	15.9	560	8.83	3.02	115.0	100.33	102.18	1.85	13.8	1196
658	8925	56.5	158	8.83	2.98	113.8	49.8	56.35	6.55	60.7	963
659	8810	48.5	182	8.72	3.03	114.5	61.18	66.88	5.70	50.5	993
660	8970	42.2	212	8.86	3.05	114.8	69.83	74.75	4.92	42.5	1036
661	8840	32.2	274	8.75	3.13	115.1	81.40	85.13	3.73	31.8	1060
662	8840	24.1	366	8.75	3.13	115.0	90.62	93.45	2.83	23.0	1068
663	8810	14.7	598	8.72	3.13	115.3	101.35	103.08	1.73	13.1	1163
664	8730	4.90	1786	8.63	3.14	115.3	111.07	111.65	0.59	3.90	1295
665	8970	5.02	1786	8.86	3.14	115.1	111.10	111.68	0.58	3.70	1403
666	8840	15.2	581	8.75	3.14	115.3	101.34	103.12	1.78	13.1	1200
667	9080	24.8	366	8.98	3.09	115.4	90.75	93.68	2.93	23.1	1113
668	8730	32.6	267	8.63	3.09	115.0	80.35	84.23	3.88	32.7	1035
669	8810	40.2	219	8.72	3.02	114.8	71.12	75.85	4.73	41.3	1008
670	8810	48.3	182	8.72	3.05	115.0	61.38	67.05	5.63	50.8	964
671	8970	7.90	1138	8.86	2 86	114.5	107.27	108.18	0.91	6.80	1200
672	8810	8.40	1057	8.72	2.88	114.4	107.27	108.25	0.98	6.60	1206
673	9000	4.80	1881	8 91	2.90	114.9	110.90	111.45	0.55	3.70	1335
674	8810	4.40	1981	8 72	2 92	114.7	111.28	111.82	0.54	3.15	1510

TABLE 5 TESTS OF HEAT TRANSFER THROUGH CONDENSER TUBES—Con.

MADE TO DETERMINE EFFECT OF VARIATIONS OF MEAN TEMPERATURE DIFFERENCE ON HEAT TRANSFER

Test Number	Circulating Water Per Hour, Lb.	Steam Condensed Per Hour, Lb.	Ratio of Water to Steam, $\frac{Q}{W}$	Velocity of Water in Tube, Ft. Per Sec.	Absolute Pressure in Condenser, In. of Mercury	Temperature of Steam, Deg. Fahr.	Temperature of Inlet Water, Deg. Fahr.	Temperature of Outlet Water, Deg. Fahr.	Temperature Rise of Water, Deg. Fahr.	Mean Temperature Difference, Deg. Fahr. —Arith.	B.t.u. Per Sq. Ft. Per Hour Per Deg. Mean Temperature Difference
	Q	W	R	V_w	p	t_s	t_0	t_1	$t_1 - t_0$	θ_m	U
Admiralty Tube, 1 in. Outside Diameter, 18 B.W.G.											
675	8970	6.70	1345	8.86	2.92	114.0	108.51	109.28	0.77	5.40	1275
676	8810	10.8	815	8.72	2.93	114.6	104.38	105.65	1.27	9.60	1165
678	8840	8.00	1101	8.75	3.05	114.7	107.99	108.93	0.94	6.20	1342
679	8890	12.1	735	8.79	3.02	113.6	102.79	104.2	1.41	10.2	1228
680	8730	12.6	690	8.64	3.10	115.3	103.88	105.38	1.50	10.7	1225
681	8970	7.50	1190	8.86	3.10	115.1	109.06	109.93	0.87	5.60	1367
682	8770	4.30	2030	8.68	3.15	115.4	111.94	112.45	0.51	3.20	1395
683	8890	7.90	1125	8.80	3.15	115.1	108.86	109.78	0.92	5.80	1405
686	6185	4.80	1294	6.12	3.10	114.6	109.80	110.6	0.80	4.40	1123
687	6030	13.9	435	5.97	3.10	114.3	99.45	101.83	2.38	13.7	1047
688	5995	21.1	284	5.93	3.04	113.4	89.83	93.48	3.65	21.7	1007
689	5995	28.6	209	5.93	3.12	115.0	81.10	86.05	4.95	31.4	945
690	5955	35.6	167	5.90	3.10	114.3	69.78	75.98	6.20	41.4	892
691	6185	42.4	146	6.12	3.10	114.2	60.73	67.83	7.10	49.9	868
692	6220	47.9	130	6.16	3.10	115.0	49.70	57.68	7 98	61.3	812
693	6300	48.5	130	6.24	3.12	114.5	49.53	57.5	7.97	61.0	823
694	6220	41.5	150	6.16	2.95	114.3	60.80	67.7	6.90	50.0	858
695	6185	36.2	171	6.12	2.95	115.3	70.25	76.3	6.05	42.0	891
696	6262	29.7	211	6.20	2.95	115.5	80.18	85.10	4.92	32.9	935
697	6340	22.0	288	6.28	2.97	114.5	89.95	93.55	3.60	22.7	1005
698	6370	13.2	481	6.31	2.95	114.5	100.38	102.53	2.15	13.0	1055
699	6185	4.30	1480	6.12	2.95	114.5	110.78	111.48	0.70	3.40	1272
700	3640	3.90	1262	3.61	2.95	114.5	110.33	111.15	0.82	3.80	786
701	3718	9.20	403	3.68	2.93	113.3	99.08	101.65	2.57	12.9	741
702	3415	10.3	233	3.38	3.08	114.3	91.33	95.78	4.45	20.7	733
703	3792	21.6	176	3.76	3.03	113.5	79.65	85.55	5.90	30.9	723
704	3718	26.5	140	3.68	3.08	114.1	71.05	78.45	7.40	39.3	700
705	3718	30.2	123	3.68	3.08	113.6	62.35	70.78	8.43	47.0	665
706	3680	33.9	108	3.64	3.08	114.0	53.73	63.28	9.55	55.5	632
707	3680	34.0	108	3.64	3.08	114.0	52.93	62.50	9.57	56.1	627
708	3562	29.8	120	3.53	3.02	113.5	59.80	68.45	8.65	49.4	625
709	3562	25.0	142	3.53	3.02	113.8	70 90	78.18	7.28	39.3	660
710	3562	20.6	173	3.53	3.03	114.0	80.25	86.23	5.98	30.8	693
711	3562	14.8	241	3.53	3.06	114.1	90.85	95.15	4.30	21.1	722
712	3562	8.40	423	3.53	2.96	113.3	100.30	102.75	2.45	11.8	740
713	3600	4.00	901	3.57	3.08	115.4	109.75	110.9	1.15	5.10	812
714	2028	21.0	97.0	2.01	2.81	112.4	51.78	62.48	10.7	55.3	392
715	1859	17.6	105	1.83	2.91	113.8	61.48	71.30	9.82	47.6	383
716	1859	14.9	124	1.83	2.86	113.0	71.08	79.4	8.32	37.7	410
717	1820	12.4	146	1.80	2.93	113.5	79.35	86.42	7.07	30.6	420
718	1915	8.80	217	1.90	2.86	112.6	90.50	95.28	4.78	19.7	478

TABLE 5 TESTS OF HEAT TRANSFER THROUGH CONDENSER TUBES—Con.

MADE TO DETERMINE EFFECT OF VARIATIONS OF MEAN TEMPERATURE DIFFERENCE ON HEAT TRANSFER

Test Number	Circulating Water Per Hour, Lb.	Steam Condensed Per Hour, Lb.	Ratio of Water to Steam, $\frac{Q}{W}$	Velocity of Water in Tube, Ft. Per Sec.	Absolute Pressure in Condenser, In. of Mercury	Temperature of Steam, Deg. Fahr.	Temperature of Inlet Water, Deg. Fahr.	Temperature of Outlet Water, Deg. Fahr.	Temperature Rise of Water, Deg. Fahr.	Mean Temperature Difference, Deg. Fahr.—Arith.	B.t.u. Per Sq. Ft. Per Hour Per Deg. Mean Temperature Difference
	Q	W	R	V_w	p	t_s	t_0	t_1	$t_1 - t_0$	θ_m	U
Admiralty Tube, 1 in. Outside Diameter, 18 B.W.G.											
719	2160	5.70	376	2.14	2.96	113.8	100.48	103.23	2.75	11.9	500
720	2160	1.90	1114	2.14	2.93	113.8	110.30	111.23	0.93	3.10	650
721	2085	1.90	1068	2.07	2.86	112.8	109.18	110.15	0.97	3.2	632
722	2102	6.10	348	2.09	2.89	112.9	99.15	102.13	2.98	12.3	510
723	1952	10.1	193	1.93	2.96	113.9	88.67	94.05	5.38	22.5	467
724	2122	14.1	151	2.10	2.91	113.1	80.58	87.43	6.85	29.1	500
725	2141	22.1	96.8	2.12	2.89	113.6	53.1	64.2	10.7	54.7	418
726	2045	18.9	108	2.03	2.89	113.5	61.85	71.4	9.55	46.9	433
727	1895	15.8	120	1.87	2.99	114.6	71.03	79.68	8.65	39.2	418

TABLE 6 TESTS OF HEAT TRANSFER

	Test Number	Circulating Water Used Per Hour, Lb.	Steam Condensed Per Hour, Lb.
Admiralty Tube, 1 In. Outside Diameter, 18 B.W.G.	728	8925	32.6
	729	8730	33.5
Copper Tube, 1 In. Outside Diameter, 16 B.W.G.	730	9080	33.6
	731	9150	33.1
Cupro-Nickel Tube, 1 In. Outside Diameter, 18 B.W.G.	732	8810	26.1
	733	9000	26.9
Old Admiralty Tube, 1 In. Outside Diameter, 18 B.W.G.	733*A*	8970	19.7
	734	8770	19.1
Aluminum-Bronze Tube, 1 In. Outside Diameter, 18 B.W.G.	735	9040	30.4
	736	8970	30.2
Monel Tube, 1 In. Outside Diameter, 18 B.W.G	737	9000	24.5
	738	9040	25.3
Aluminum-Lined Tube, 1 In. Outside Diameter, 18 B.W.G.	739	8840	33.5
	740	9080	33.9
Shelby Steel Tube, 1 In. Outside Diameter, 18 B.W.G.	741	9040	22.8
	742	8840	22.0
Admiralty Lead-Lined, 1 In. Outside Diameter, 0.083 In. Thick	743	8650	27.6
	744	8810	27.3
Admiralty-Oxidised, 1 In. Outside Diameter, 18 B.W.G.	745	8890	30.8
	746	9040	32.0
Zinc Tube, 1 In. Outside Diameter, 18 B.W.G.	747	8925	26.0
	748	8970	25.7
Tin Tube, 1 In. Outside Diameter, 0.055 In. Thick	749	8840	27.7
	750	8970	27.2
Admiralty Tube, 1 In. Outside Diameter, 18 B.W.G.	751	9080	105
	752	8970	101
	753	8890	93.1
	754	8925	82.7
	755	9120	70.5
	756	8770	62.0
	757	8890	104
	758	8620	95.7
	759	8840	89.0
	760	8770	80.5
	761	8730	70.5
	762	8890	59.8
Copper Tube, 1 In. Outside Diameter, 16 B.W.G.	763	8925	51.3
	764	9040	71.1
	765	9080	99.4
	766	8970	117
	767	9000	138
Admiralty, Vulc. Inside, 1 In. Outside Diameter, 18 B.W.G.	768	8730	177
	769	8730	186
Admiralty, Vulc. Both Sides, 1 In. Outside Diameter, 18 B.W.G.	770	8770	6.4
	771	9040	6.6

THROUGH CONDENSER TUBES

Ratio of Water to Steam	Velocity of Water in Tube, Ft. Per. Sec.	Absolute Pressure in Condenser, In. of Mercury	Temperature of Steam, Deg. Fahr.	Temperature of Inlet Water, Deg. Fahr.	Temperature of Outlet Water, Deg. Fahr.	Temperature Rise of Water, Deg. Fahr.	Mean Temperature Difference, Deg. Fahr.—Arith.	B.t.u. Per Sq. Ft. Per Hour Per Deg. Mean Temperature Difference
274	8.83	2.81	114.4	85.75	89.53	3.78	28.8	1257
260	8.62	2.86	115.7	85.50	89.48	3.98	28.2	1232
270	9.38	2.96	114.7	85.40	89.23	3.83	27.4	1267
276	9.42	2.81	114.3	84.78	89.53	3.75	27.6	1243
337	8.71	2.99	114.9	86.03	89.1	3.07	27.3	968
334	8.90	2.93	114.1	85.38	88.48	3.10	27.2	1024
456	8.87	2.96	114.8	84.58	86.85	2.27	29.1	703
460	8.67	2.96	114.6	85.45	87.70	2.25	28.0	705
296	8.94	3.12	119.0	85.45	88.98	3.48	28.8	1090
298	8.87	3.05	114.9	84.62	88.10	3.48	28.5	1092
368	8.90	2.99	113.8	85.18	88.00	2.82	27.2	982
357	8.94	2.99	114.5	84.92	87.82	2.90	28.1	932
264	8.99	2.96	115.3	84.90	88.82	3.93	28.4	1223
296	9.21	2.96	115.0	85.26	89.15	3.87	27.8	1262
395	8.94	3.07	115.6	84.68	87.50	2.63	29.4	805
401	8.75	2.99	115.1	85.60	88.18	2.58	28.2	806
309	10.00	3.01	115.1	85.10	88.45	3.35	28.3	1023
322	10.20	2.99	114.9	85.53	88.75	3.28	27.6	1022
288	8.79	3.07	115.3	85.38	88.98	3.60	28.1	1136
283	8.94	3.04	115.0	85.15	88.82	3.67	28.0	1183
343	8.83	3.07	115.6	85.28	88.00	3.02	28.1	966
348	8.87	3.07	115.0	85.45	88.45	2.97	28.0	948
318	8.94	3.14	115.9	86.00	89.25	3.25	28.3	1015
329	9.07	3.07	115.0	85.48	88.63	3.15	27.9	1009
86.6	8.98	9.70	161.3	53.30	64.83	11.53	103.2	1027
89.0	8.87	9.68	160.3	53.55	64.85	11.29	101.1	1000
95.5	8.79	9.68	160.0	63.98	74.48	10.5	90.8	1027
106	8.83	9.57	159.3	77.93	87.2	9.27	76.6	1078
129.4	9.02	9.72	160.5	93.00	100.75	7.75	63.6	1106
141.2	8.67	9.75	160.6	101.80	108.9	7.10	55.2	1127
85.4	8.79	9.84	161.3	55.33	67.08	11.75	100.1	1040
90.0	8.52	9.78	161.1	63.50	73.65	11.15	93.0	1033
99.4	8.75	9.85	161.0	72.60	83.7	10.1	83.3	1070
109	8.68	9.71	160.3	81.35	90.45	9.2	74.4	1063
124	8.64	9.73	160.0	92.93	101.03	8.10	63.0	1120
149	8.79	9.75	160.5	106.50	113.24	6.75	50.7	1182
173	9.25	3.02	114.9	56.68	62.7	6.02	54.2	993
127	9.36	4.97	134.0	56.63	64.68	8.05	73.3	1006
91.4	9.37	9.82	160.7	56.85	67.83	10.98	96.3	1015
76.4	9.30	14.79	178.1	56.50	69.45	12.95	115.1	1007
65.1	9.34	22.52	197.0	56.65	71.65	15.00	133.3	1017
49.2	8.65	3.00	117.8	85.95	88.05	2.10	30.8	596
47.0	8.65	3.00	117.2	84.45	86.65	2.20	31.6	607
1380	8.68	3 02	115 7	85.48	86.23	0.75	30.0	219
1380	8.94	3 07	115 9	85.95	86.70	0.75	29.7	227

TABLE 7 CONDENSER TESTS*

MADE ON A CYLINDRICAL SURFACE CONDENSER CONTAINING 300 SQ. FT. OF TUBE SURFACE

Test Number	Steam Condensed Per Hour, Lb.	Ratio of Water to Steam, $\frac{Q}{W}$	Velocity of Water in Tubes, Ft. Per Sec.	Absolute Pressure in Condenser, In. of Mercury	Temperature of Steam, Deg. Fahr.	Temperature of Inlet Water, Deg. Fahr.	Temperature of Discharge Water, Deg. Fahr.	Temperature Rise Water, Deg. Fahr.	Mean Temperature Difference, Deg. Fahr.	Ratio of Length in Ft. to Diameter in In.	B.t.u. Per Sq. Ft. Per Deg. Fahr. Difference Per Hour
	W	R	V_w	p	t_s	t_0	t_1	t_1-t_0	θ	$l+d$	U
1	1504	122.0	0.952	2.15	106.7	85.0	93.0	8.0	17.4	15.657	281
2	1484	101.2	0.780	2.33	107.7	85.6	95.2	9.6	16.8	15.657	286
3	1495	80.3	0.620	2.5	110.5	85.5	98.0	12.5	18.05	15.657	275
4	1503	61.1	0.476	3.08	117.5	86.0	103.0	17.0	21.95	15.657	237
5	1469	51.5	0.393	3.42	121.0	85.0	107.0	22.0	23.32	15.657	237
6	1552	107.0	0.862	2.0	104.7	80.0	90.0	10.0	19.27	15.657	293
7	1487	95.7	0.738	2.11	104.3	79.2	91.8	12.6	18.05	15.657	332
8	1533	83.0	0.655	2.31	107.4	80.09	94.6	14.51	19.13	15.657	321
9	1497	61.4	0.478	2.73	112.8	81.6	98.1	16.5	21.95	15.657	224
10	1537	49.25	0.393	3.19	117.8	80.0	100.9	20.9	25.98	15.657	199
11	1590	114.0	0.942	1.82	100.0	74.5	83.5	9.0	20.7	15.657	263
12	1542	78.0	0.624	2.09	104.8	75.0	88.5	13.5	22.35	15.657	242
13	1595	60.2	0.498	2.45	109.2	75.1	93.9	18.8	23.42	15.657	245
14	1514	39.65	0.312	3.29	119.6	74.97	101.4	26.43	29.5	15.657	180
15	1600	103.5	0.861	1.58	94.2	70.0	80.0	10.0	18.73	15.657	293
16	1502	69.5	0.547	1.93	101.0	70.0	85.4	15.4	22.45	15.657	238
17	1529	49.5	0.393	2.55	113.3	70.0	92.7	22.7	30.6	15.657	187
18	1510	39.8	0.309	3.12	117.5	70.0	98.5	28.5	31.1	15.657	183
19	1560	106.0	0.860	1.23	88.7	65.0	74.5	9.5	18.5	15.657	288
20	1601	66.0	0.550	1.91	103.0	65.05	81.4	16.35	29.05	15.657	198
21	1520	49.7	0.393	2.32	111.9	64.2	86.7	22.5	35.35	15.657	161
22	1495	40.2	0.312	2.93	115.5	65.06	91.8	26.74	35.5	15.657	151
23	2050	96.8	1.030	2.48	108.6	85.0	96.4	11.4	17.28	15 657	436
24	1993	79.5	0.812	2.8	113.34	84.64	98.8	14.16	20.83	15.657	335
25	2054	59.2	0.631	3.36	118.9	85.04	103.96	18.92	23.15	15.657	327
26	1998	49.5	0.875	3.67	122.5	84.9	108.32	23.42	24.03	15.657	322
27	1964	101.0	1.030	2.28	106.6	81.1	92.9	11.8	19.0	15.657	412
28	1983	80.0	0.825	2.44	108.3	80.9	95.5	14.6	19.19	15.657	402
29	2038	58.93	0.622	2.97	114.3	80.1	99.0	18.9	23.5	15.657	322
30	2068	47.7	0.512	3.45	119.5	80.0	101.6	21.6	27.32	15.657	260
31	1908	95.0	0.940	2.14	103.3	75.0	87.2	12.2	21.65	15.657	341
32	1993	79.5	0.823	2.25	107.0	75.7	90.7	15.0	23.0	15.657	345
33	1986	49.75	0.510	2.82	114.5	75.0	98.0	23.0	26.35	15.657	288
34	2009	39.1	0.407	3.51	120.3	75.0	103.0	28.0	29.1	15.657	246
35	2016	111.5	1.170	1.64	95.0	70.2	78.8	8.6	20.2	15.657	320
36	2076	76.0	0.825	2.03	104.4	70.3	83.8	13.5	26.8	15.657	265
37	2017	66.8	0.700	2.1	105.5	70.3	87.3	17.0	25.8	15.657	297
38	1992	60.25	0.622	2.08	103.9	68.5	86.15	17.65	25.6	15.657	276
39	1963	50.25	0.512	2.53	110.0	70.0	91.4	21.4	27.95	15.657	252
40	2029	38.7	0.408	3.27	119.4	70.0	98.3	28.3	33.3	15.657	221
41	2106	94.2	1.030	1.52	92.2	65.0	76.0	11.0	21.2	15.657	343

*Tests made by R. W. Allen and published in Proc., Inst. C. E., Feb. 28, 1905

TABLE 7 CONDENSER TEST—Con.

MADE ON A CYLINDRICAL SURFACE CONDENSER CONTAINING 300 SQ. FT. OF TUBE SURFACE

Steam Condensed Per Hour, Lb.	Ratio of Water to Steam, $\frac{Q}{W}$	Velocity of Water in Tube, Ft. Per Sec.	Absolute Pressure in Condenser, In. of Mercury	Temperature of Steam, Deg. Fahr.	Temperature of Inlet Water, Deg. Fahr.	Temperature of Discharge Water, Deg. Fahr.	Temperature Rise Water, Deg. Fahr.	Mean Temperature Difference, Deg. Fahr.	Ratio of Length in Ft. to Diameter in In.	B.t.u. Per Sq. Ft. Per Deg. Fahr. Difference Per Hr.
W	R	V_w	p	t_s	t_0	t_1	$t_1 - t_0$	θ	$l \div d$	U
2008	79.0	0.824	1.70	96.0	65.0	78.3	13.3	23.8	15.657	296
2154	55.73	0.623	2.10	103.5	65.0	82.7	17.7	28.78	15.657	246
1932	40.7	0.408	2.89	114.0	65.0	90.7	25.7	34.63	15.657	195
2440	121.0	1.535	2.48	107.7	85.0	92.7	7.7	18.6	15.657	407
2460	91.25	1.161	2.72	111.7	85.0	95.0	10.0	21.3	15.657	351
2520	78.8	1.032	2.98	113.5	84.75	96.8	12.05	22.2	15.657	360
2428	60.3	0.764	3.45	119.0	84.6	100.8	16.2	25.41	15.657	311
2520	117.3	1.532	2.15	103.2	80.1	88.6	8.5	18.55	15.657	453
2600	94.25	1.273	2.38	106.3	80.0	90.5	10.5	20.62	15.657	417
2580	77.0	1.044	2.71	110.8	80.5	94.1	13.6	22.85	15.657	394
2500	60.0	0.780	3.09	116.0	80.0	96.7	16.7	26.83	15.657	310
2580	118.5	1.589	1.84	99.7	75.0	83.0	8.0	20.4	15.657	400
2460	99.7	1.274	2.06	102.0	75.25	85.0	9.75	21.53	15.657	370
2484	80.0	1.032	2.33	106.4	74.9	87.4	12.5	24.75	15.657	339
2565	58.5	0.778	2.96	112.5	75.0	93.0	8.0	12.25	15.657	327
2520	39.1	0.512	3.88	123.6	75.0	100.3	25.3	34.42	15.657	241
2620	115.3	1.571	1.72	95.0	70.1	78.7	8.6	20.25	15.657	427
2424	101.0	1.272	1.81	98.2	69.7	79.0	9.3	23.6	15.657	322
2520	78.8	1.032	2.15	103.3	70.0	83.0	13.0	26.3	15.657	327
2468	40.0	0.512	3.54	120.2	70.0	95.7	25.7	35.8	15.657	236
2445	121.0	1.538	1.40	90.5	65.1	73.0	7.9	21.25	15.657	322
2400	93.5	1.165	1.65	94.2	64.7	74.7	10.0	24.2	15.657	309
2430	61.75	0.778	2.17	104.7	65.0	83.0	18.0	29.8	15.657	302
2515	39.3	0.512	3.22	117.2	65.0	91.0	26.0	37.75	15.657	228
2916	105.0	1.590	2.70	110.6	85.0	94.6	9.6	20.41	15.657	482
3041	80.5	1.270	2.97	113.6	85.0	97.0	12.0	22.08	15.657	438
2964	69.7	1.073	3.30	117.9	85.0	99.0	14.0	25.25	15.657	382
2968	58.5	0.901	3.68	121.8	84.9	102.2	17.3	27.39	15.657	366
3012	98.5	1.538	2.40	107.2	80.1	90.0	9.9	21.77	15.657	448
2960	84.75	1.303	2.60	109.0	80.0	91.6	11.6	22.75	15.657	427
2952	59.0	0.905	3.28	117.0	80.0	96.7	16.7	27.9	15.657	348
3048	106.5	1.689	1.94	101.0	75.0	83.0	8.0	21.8	15.657	397
3015	98.5	1.541	2.09	102.7	75.0	84.2	9.2	22.8	15.657	400
2970	81.7	1.260	2.28	106.2	75.0	87.0	12.0	24.4	15.657	398
2940	61.5	0.938	2.66	110.7	75.0	91.5	16.5	26.58	15.657	376
3015	49.75	0.778	3.34	118.75	75.0	96.0	21.0	32.1	15.657	326
3012	107.8	1.690	1.78	97.1	70.3	79.1	8.8	22.02	15.657	434
3000	99.0	1.538	1.83	99.1	70.25	80.25	10.0	23.5	15.657	421
2970	61.0	0.942	2.56	111.0	70.0	86.7	16.7	32.0	15.657	315
3171	37.9	0.624	3.82	122.5	69.7	96.2	26.5	38.1	15.657	277
2970	90.7	1.400	1.70	95.6	64.6	75.2	10.6	25.3	15.657	376
2965	69.5	1.070	2.03	101.3	65.0	79.5	14.5	28.35	15.657	351
3077	48.75	0.770	2.74	111.6	65.0	86.4	21.4	34.78	15.675	307

TABLE 8 HEATER TESTS *

Test Number	Circulating Water Per Hour, Lb.	Ratio of Water to Steam, $\frac{Q}{W}$	Total Tube Surface, Sq. Ft.	Ratio of Length in Ft. to Diameter in In.	Velocity of Water in Tubes, Ft. Per Sec.	Temperature of Steam, Deg. Fahr.	Temperature of Inlet Water, Deg. Fahr.	Temperature of Discharge Water, Deg. Fahr.	Temperature Rise of Water, Deg. Fahr.	$\text{Log}_e \frac{t_s - t_0}{t_s - t_1}$	Mean Temperature Difference, Deg. Fahr.	B.t.u. Per Sq. Ft. Per Deg. Difference Per Hour	Remarks
	Q	R	S	$l \div d$	V_w	t_s	t_0	t_1	$t_1 - t_0$		θ	U	
1	176	20.0	0.1964	3.00	0.867	212	47.8	96.7	48.9	0.3528	138.5	314	
2	357	32.1	0.1964	3.00	1.76	212	47.8	78.0	30.2	0.2045	147.7	376	Stanton
3	464	36.5	0.1964	3.00	2.29	212	46.7	73.2	26.5	0.1747	151.8	411	One copper tube, 0.5 in. outside
4	806	48.8	0.1964	3.00	3.97	212	54.3	74.1	19.8	0.1336	148.2	547	diameter, 19 B.W.G., 18 in. long,
5	176	15.5	0.1964	3.00	0.867	212	47.8	110.3	62.5	0.4811	130	430	tube in vertical position. Water
6	357	27.5	0.1964	3.00	1.76	212	47.8	83.0	35.2	0.2422	145.1	439	circulated up in Tests 1-4, down
7	464	31.4	0.1964	3.00	2.29	212	46.7	77.5	30.8	0.2070	148.7	489	in Tests 5-8
8	806	46.9	0.1964	3.00	3.97	212	54.3	74.9	20.6	0.1398	147.2	573	
9	702	11.22	1.065	7.23	1.33	255	58.0	140	82.0	0.5377	153.2	356	Nichols
10	2421	26.4	1.065	7.23	4.60	255	58.0	93.5	35.5	0.1988	178.6	452	One brass tube, 0.75 in. outside
11	3393	34.7	1.065	7.23	6.44	256	58.0	85.0	27.0	0.1467	184	467	diameter, 18 B.W.G., 65 in.
12	675	8.75	1.065	7.23	1.28	253	57.8	165	107.2	0.7975	134.5	505	long. Tube vertical in Tests
13	2670	21.8	1.065	7.23	5.06	253	58.0	101	43.0	0.2484	173	622	9-11, horisontal in Tests 12-14.
14	3612	25.6	1.065	7.23	6.85	254	58.0	94.5	36.5	0.2058	177.4	698	Water ran up in Tests 9-11

15	1216	8.12	13.09	16.0	0.373	212	74.0	193	119	1.9831	60	184	
16	1342	9.11	13.09	16.0	0.412	212	74.0	180	106	1.4609	72.5	150	
17	2870	10.07	39.27	16.0	0.294	212	74.0	170	96.0	1.1894	80.7	86.9	Hepburn
18	2252	7.87	39.27	16.0	0.222	212	72.0	195	123	2.1090	58.3	123	Copper tubes, 1.25 in. outside diameter, 18 B.W.G., 20 in. long. Tubes horizontal. Corrugated tubes in Tests 24-27. Tests 20-23, 1 tube: Tests 15, 16, 26, 27, 2 tubes Tests 17-19, 24-25, 6 tubes
19	1548	7.44	39.27	16.0	0.158	211	74.0	204	130	2.9745	43.7	117	
20	3082	9.73	6.045	16.0	1.89	217	71.0	170	99	1.1346	87.1	580	
21	2464	9.64	6.045	16.0	1.51	216	72.0	172	100	1.1860	84.3	484	
22	3708	10.60	6.045	16.0	2.275	216	71.0	162	91	0.9877	92.1	606	
23	1084	9.47	6.045	16.0	0.666	214	72.0	174	102	1.2669	80.6	227	
24	3930	5.93	45.2	16.0	0.402	211	41.0	204	163	3.1905	51.1	277	
25	4006	5.89	45.2	16.0	0.410	212	40.0	204	164	3.1294	52.4	277	
26	4440	7.53	15.07	16.0	1.361	215	67.0	195	128	2.0015	63.9	591	
27	3530	7.20	15.07	16.0	1.082	214	66.0	200	134	2.3582	56.9	542	
28	2799	6.65	54.2	3.333	0.048	215	62.0	207	145	2.9502	49.1	152	
29	3965	6.92	54.2	3.333	0.068	215	62.0	201.3	139.3	2.4132	57.8	176	
30	5223	7.36	54.2	3.333	0.090	215	62.0	193	131	1.9402	67.5	187	
31	5162	7.30	54.2	3.333	0.089	215	62.0	194.3	132.3	2.0001	66.6	189	
32	2558	6.58	54.2	3.333	0.044	215	62.0	208.5	146.5	3.1591	46.6	148	
33	3069	6.67	54.2	3.333	0.053	215	62.0	206.5	144.5	2.8903	50	164	Hildreth
34	3993	6.92	54.2	3.333	0.069	215	62.0	201.3	139.3	2.4123	57.8	177	Corrugated copper tubes, 1.5 in. outside diameter, 18 B.W.G. Vertical position, water circulated up. Tests 28-36, 24 tubes, 5 in. long. Tests 37-44, 36 tubes, 6 ft. 2 in. long.
35	4950	7.25	54.2	3.333	0.086	215	62.0	195.3	133.3	2.0503	65.1	187	
36	4805	7.15	54.2	3.333	0.083	215	62.0	197	135	2.1401	63.1	190	
37	1215	6.46	100.	4.10	0.014	215	62.0	211.3	149.3	3.7220	40.1	45.7	
38	3296	6.47	100.	4.10	0.038	215	62.0	211	149	3.6433	40.9	120	
39	3807	6.51	100.	4.10	0.044	215	62.0	210	148	3.4209	43.2	130	
40	4468	6.60	100.	4.10	0.0513	215	62.0	208	146	3.0842	47.3	138	
41	5879	6.75	100.	4.10	0.0675	215	62.0	205	143	2.7278	52.4	160	
42	5387	6.84	100	4.10	0.0735	215	62.0	203	141	2.5447	55.4	162	
43	7128	6.95	100.	4.10	0.082	215	62.0	200.8	138.8	2.3768	58.5	169	
44	7869	7.08	100.	4.10	0.091	215	62.0	198	136	2.1972	62.0	173	
45	4111	5.77	33.35	16.4	0.567	219	45.0	211.8	166.8	3.1201	53.4	385	Richter
46	5231	5.54	33.35	16.4	0.722	229	43.0	215.2	172.2	2.5810	66.7	406	3 corrugated copper tubes, 15 in. outside diameter, 18 B.W.G., 24 ft. 8 in. long. Horizontal.
47	3936	5.22	33.35	16.4	0.543	233	45.0	227	182	3.4442	52.8	407	

* Tests made by H. L. Hepburn and published in Power, Vol. 21, p. 15.

TABLE 9 HEAT TRANSMISSION TESTS*

Table Number	Test Number	Circulating Water Per Hour, Lb. Q	Ratio of Water to Steam, $\frac{Q}{W}$ R	Velocity, Ft. Per Sec. V_w	Absolute Pressure, Lb. Per Sq. In. p	Steam Temperature, Deg. Fahr. t_s	Water Temperature In, Deg. Fahr. t_0	Water Temperature Out, Deg. Fahr. t_1	Rise of Temperature, Deg. Fahr. t_1-t_0	$\log_e \frac{t_s-t_0}{t_s-t_1}$	Mean Difference of Temperature, Deg. Fahr. θ	B.t.u. Per Sq. Ft. Per Deg. Difference Per Hour. U
Brass Tube 37.0 In. Long, 1.93 In. Outside Diameter, 0.0788 In. Thick, Enclosing a Closed Tube 1.515 In. Outside Diameter												
Outer Tube Water Area, 0.00467 Sq. Ft. Surface, 1.56 Sq. Ft. $\frac{l}{d}=1.6$												
	4	305	12.1	0.29	14.7	212	79.0	159.0	80.0	0.9203	86.9	180
	5	305	11.96	0.29	14.7	212	78.5	159.3	80.8	0.9282	87.0	181
	6	468	17.0	0.446	14.7	212	90.0	146.7	56.7	0.6259	90.6	188
	7	463	17.3	0.44	14.7	212	90.0	146.0	56.0	0.6152	91.0	183
	8	832	24.6	0.793	14.7	212	98.6	137.9	39.3	0.4253	92.4	227
2	9	868	24.5	0.826	14.7	212	98.3	137.7	39.4	0.4253	92.7	236
	10	2660	36.6	2.63	14.7	212	106.4	132.8	26.4	0.2867	92.1	488
	11	2605	36.3	2.49	14.7	212	106.2	132.8	26.6	0.2897	91.9	488
	11a	4060	46.2	3.87	14.7	212	106.4	127.3	20.9	0.2199	95.1	572
	11b	5740	62.0	5.47	14.7	212	109.0	124.6	15.6	0.1655	94.3	609
	11c	5840	57.5	5.56	14.7	212	106.2	123.0	16.8	0.1722	97.5	645
	11d	5975	74.4	5.69	14.7	212	123.4	136.4	13.0	0.1578	83.4	605
	12	1026	113.8	0.976	14.7	212	192.0	200.5	8.5	0.5530	15.3	365
	13	1026	94.8	0.976	14.7	212	187.5	197.7	10.2	0.5385	18.9	355
	14	1037	50.8	0.987	14.7	212	164.0	183.0	19.0	0.5032	37.8	334
	15	1022	33.6	0.974	14.7	212	134.3	163.0	28.7	0.4605	68.3	302
	16	1060	28.1	1.00	14.7	213	118.1	152.4	34.3	0.4479	76.6	308
3					14.7	213	104.0	142.8	38.8	0.4256	89.4	298

	23	2107	122.3	2.01	14.7	212	186.9	194.8	7.9	0.3784	20.8	513
	24	2107	57.9	2.01	14.7	212	159.0	175.7	16.7	0.3784	44.0	513
4	25	2098	59.3	2.00	14.7	212	158.5	174.8	16.3	0.3633	44.9	488
	26	2098	42.6	2.00	14.7	212	131.3	154.0	22.7	0.3300	68.8	444
	27	2110	34.8	2.10	14.7	212	105.0	132.8	27.8	0.3001	92.7	405
	28	2115	34.6	2.13	14.7	212	87.3	115.2	27.9	0.2531	110.2	343
	29	2098	28.5	2.00	14.7	212	49.6	83.5	33.9	0.2335	145.1	314
	30	3406	261.0	3.24	14.7	212	195.5	199.2	3.7	0.2546	14.51	555
	31	3370	276.0	3.21	14.7	212	195.5	199.0	3.5	0.2390	14.62	517
	32	3340	241.5	3.18	14.7	212	188.8	192.8	4.0	0.1894	21.1	406
5	33	3450	56.8	3.28	14.7	212	141.0	158.0	17.0	0.2723	62.4	603
	34	3424	42.9	3.26	14.7	212	110.3	132.8	22.5	0.2484	90.5	547
	35	3395	34.0	3.23	14.7	212	49.1	77.5	28.4	0.1906	149.0	414
	36	5415	312.0	5.16	14.7	212	193.5	196.6	3.1	0.1823	17.0	633
	37	5480	84.8	5.22	14.7	212	161.5	173.9	11.4	0.2554	44.6	887
6	38	5525	60.4	5.26	14.7	212	127.0	143.0	16.0	0.2078	77.0	737
	39	5415	42.6	5.16	14.7	212	49.3	72.0	22.7	0.1484	153.0	515
	40	5560	45.1	5.30	14.7	212	49.3	70.7	21.4	0.1398	153.0	498
	72–73	4710	37.3	4.48	14.7	212	43.5	69.4	25.9	0.1663	155.7	503
	74	4710	34.5	4.48	17.5	221	44.2	72.0	27.8	0.1697	164.0	512
11	75	4710	31.3	4.48	23.0	236	44.2	74.5	30.3	0.1714	176.8	518
	76–77	4710	26.0	4.48	34.2	257.9	43.6	79.5	35.9	0.1831	196.0	554
	78–79	4630	25.3	4.41	39.3	266	43.3	79.9	36.6	0.1747	209.5	518
	81	2055	15.8	1.96	32.3	254.1	43.7	103.0	59.3	0.3300	179.6	435
	82	2055	16.8	1.96	28.8	248	43.7	99.5	55.8	0.3193	174.3	421
	83	2055	18.6	1.96	23.0	236	43.7	94.7	51.0	0.3075	166.0	404
	84	2055	21.6	1.96	17.5	221	43.3	87.8	44.5	0.2860	155.5	377
12	85	2100	24.7	2.00	14.7	212	43.7	82.8	39.1	0.2639	148.1	355
	86	2067	26.6	1.97	13.2	206.6	43.7	80.2	36.5	0.2538	144.0	336
	87	2080	26.8	1.98	12.5	203.9	43.7	79.9	36.2	0.2561	141.1	342
	88	2055	31.5	1.96	9.4	190.4	43.7	74.9	31.2	0.2390	130.8	314

*Tests made by Gustav Hagemann and published in the Proc., Inst. C. E., vol. 77, 1883.

TABLE 10 CONDENSER TUBE

Test Number	Steam Condensed Per Hour	Ratio of Water to Steam, $\frac{Q}{W}$	Velocity of Water in Tube, Ft. Per. Sec.	Absolute Pressure in Condenser, In. of Mercury	Temperature of Steam, Deg. Fahr.	Hot-Well Temperature, Deg. Fahr.	Temperature of Inlet Water, Deg. Fahr.	Temperature of Outlet Water, Deg. Fahr.
	W	R	V_w	p	t_s	t_p	t_i	t_p
1	2.374	41.1	0.057	1.56	93.3	91.55	41.33	66.40
2	5.818	17.0	0.58	5.00	134.	131.5	41.33	104.7
3	18.93	40.0	0.442	17.99	187.3	174.0	41.28	66.60
4	17.83	44.7	0.465	15.32	180.0	167.5	40.93	63.78
5	11.21	53.7	0.346	9.09	157.7	142.9	40.62	61.05
6	15.50	40.8	0.369	13.33	174.0	157.9	40.66	66.55
14	4.36	15.6	0.040	29.90	212.	75.03	41.68	119.1
17	2.985	63.5	0.798	0.96	78.0	73.0	43.83	61.7
18	2.983	6.85	0.086	18.33	188.2	183.8	43.20	178.0
19	3.27	13.3	0.184	4.97	133.7	129.9	43.91	123.1
20	1.83	33.4	0.258	1.19	84.5	78.3	44.35	78.15
21	11.46	6.67	0.322	25.13	203.3	189.0	43.45	190.6
34	14.81	44.3	2.67	2.16	104	103.5	47.59	72.6
35	30.84	40.3	5.24	7.88	151.7	140.8	47.51	73.33
62	7.40	64.0	5.00	1.115	82.6	78.65	42.93	61.80
63	23.79	20.7	5.20	7.29	148.7	138.0	42.93	94.70
64	44.75	12.1	5.72	27.27	207.2	190.1	42.93	124.6
39	3.023	19.0	0.670	2.19	104.4	103.2	44.11	101.7
40	3.629	5.90	0.226	24.49	202	193.0	45.09	192.5
41	3.399	39.3	1.41	1.04	80.5	77.15	44.82	78.15
42	10.52	14.7	1.63	6.06	141.3	121.2	44.38	117.8
43	8.737	11.4	1.05	6.93	146.7	143.4	44.51	134.2
47	5.559	31.9	4.80	1.59	93.85	60.18	43.71	57.80
65	5.01	30.1	1.59	1.82	98.2	82.95	44.55	80.30
66	13.05	14.2	1.95	5.45	137.1	133.	44.55	118.0
67	25.81	8.25	2.24	22.77	198.7	186.5	44.55	160.2
68	3.22	9.18	0.146	10.06	161.9	149.2	48.91	153.2
70	22.18	18.1	2.07	21.53	196.0	178.0	48.44	107.1
73	27.75	23.6	3.25	21.07	194.9	179.3	45.13	87.4
75	2.65	235.	3.09	1.18	84.45	65.4	45.02	50.56
83	3.284	6.99	0.114	30.02	212.3	96.0	41.00	195.2
84	26.43	21.0	2.17	28.52	209.7	201.2	56.40	102.0
85	23.75	19.2	1.78	29.54	211.5	192.3	56.40	108.15
97	11.81	47.7	0.842	4.04	126.1	120.9	62.40	85.15
98	27.31	24.2	0.990	14.45	177.4	168.7	62.00	105.25
99	38.01	20.6	1.17	24.49	202.0	190.6	61.60	111.2
148	5.14	23.2	1.44	1.601	94.1	91.1	40.50	88.00
149	13.63	10.1	1.66	8.39	154.2	150.	40.50	142.2
150	9.71	35.0	4.10	1.412	90.1	82.5	39.56	70.4
151	23.36	14.9	4.22	7.192	148.0	144.3	39.56	109.0

* Tests made by J. P. Joule and published in Phil. Trans. Royal Soc., Vol. 151, p. 133.

ANSFER TESTS*

Mean Temperature Difference, Deg. Fahr.	Ratio of Length in Ft. to Diameter in In.	B.t.u. Per Sq. Ft. Per Deg. Fahr. Per Hour	Remarks
θ	$l \div d$	U	
36.85	6.35	108.7	
55.0	6.35	172	
133	6.36	219	Copper steam tube, 4 in. long, 0.75 in. outside diameter, 0.63 in. inside diameter. Total inside surface, 0.66 sq. ft. Water area, 1.0976 sq. in. Outer tube 1.4 in. inside diameter. Flow counter-current.
128.2	6.35	216	
107.1	6.35	171	
120.2	6.35	206	
127.2	6.35	62.5	
24.2	6.35	212	
50.8	6.35	82	
37.1	6.35	141	Same steam tube. Outer tube 0.87 in. inside diameter. Water area 0.1523 sq. in. Flow counter-current except Tests 34 and 35, in which steam and water flow in the same direction.
18.3	6.35	171	
58.1	6.35	293.5	
42.8	6.35	349	
90.6	6.35	538	
29.4	6.35	460	Same steam tube. Outer tube 0.8 in. inside diameter. Inner tube rubbed with oil. Water area 0.0609 sq. in. Flow counter-current.
77.0	6.35	503	
118.6	6.35	566	
18.5	6.35	271	
52.5	6.35	91	
17.9	6.35	320	Same steam tube. Outer tube 0.8 in. inside diameter Water area 0.0609 sq. in. Counter-current.
51.9	6.35	332	
42.6	6.35	317	
42.9	6.35	226	
32.6	6.35	250	Same tubes. Oil cleaned off after tests 62–64. Water and steam in same direction.
46.5	6.35	442	
81.8	6.35	456	
40.7	7.69	139	Lead tube 4 ft. long, 0.77 in. outside diameter, 0.52 in. inside diameter. Outer tube 0.87 in. inside diameter. Inside surface 0.545 sq. ft. Water area 0.1288 sq. in. Counter-current flow.
115.7	7.69	389	
127.8	7.69	398	
36.7	7.69	173	
67.0	7.69	97	
128.7	6.65	313	Iron tube 4 ft. long, 0.74 in. outside diameter, 0.602 in. inside diameter. Outer tube 0.87 in. inside diameter. Surface 0.63 sq. ft. Water area 0.164 sq. in. Counter-current.
127.5	6.65	294	
51.5	6.35	377	Copper tube again. Outer tube 1.4 in. inside diameter. Spiral 0.1 in. diameter copper wire 30 turns around inner tube—half l.h. Water area 0.429 sq. in. Counter-current.
92.1	6.35	470	
113.5	6.35	518	
20.8	6.65	431	Iron tube as above. Outer tube 0.87 in. inside diameter. Spiral of 55 turns 0.055 in. copper wire wound on inner tube. Water area 0.053 sq. in. Tests 148-149, steam and water in same direction. Tests 150-151, counter-current.
45.2	6.65	492	
32.8	6.65	507	
67.9	6.65	566	

TABLE 11 CONDENSER TESTS*

SURFACE = 25,000 SQ. FT. TWO PASS. WATER AREA 13.22 SQ. FT. 5960 TUBES, 16 FT. LONG, OUTSIDE DIAMETER, 18 B.W.G.

Test Number	Steam Condensed Per Hour, Lb. W	Ratio of Water to Steam, $R = \frac{Q}{W}$	Absolute Pressure of Steam, In. of Mercury p	Velocity of Water, Ft. Per Sec. V_w	Temperature of Steam, Deg. Fahr. t_s	Hot-Well Temperature, Deg. Fahr. t_p	Temperature of Inlet Water, Deg. Fahr. t_0	Temperature of Outlet Water, Deg. Fahr. t_1	Temperature of Rise Water, Deg. Fahr. $t_1 - t_0$	$\frac{t_s - t_0}{\text{Log}_e \frac{t_s - t_0}{t_s - t_1}}$ log	Mean Temperature Difference, Deg. Fahr. θ
38	237480	53.5	1.51	42.7	92	71.2	37.7	57.3	19.6	0.445	43.8
39	187193	48.2	1.59	3.04	94	76.2	39.9	62.5	22.6	0.542	41.7
40	170661	52.9	1.22	3.04	85	71.0	32.0	51.8	19.8	0.470	42.1
41	160229	46.4	1.30	2.50	87	73.4	34.0	56.8	22.8	0.565	40.3
42	147142	42.7	1.32	2.11	88	75.2	31.8	56.7	24.9	0.588	42.4
43	138766	44.2	1.47	2.06	91	80.2	32.8	57.1	24.3	0.542	44.8
44	122689	107.7	0.94	4.44	77	59.4	31.6	42.0	10.4	0.262	39.6
48	114372	118	1.20	4.54	85	60.6	32.9	42.1	9.2	0.1906	48.3
51	133462	150	1.18	6.72	84	65.2	37.5	43.1	5.6	0.1310	42.7
54	176565	77.1	0.94	4.57	77	57.3	33.5	47.8	14.3	0.3988	35.6
55	99210	112	1.16	3.73	84	58.6	33.1	41.3	8.2	0.1740	47.1
56	158112	63.4	1.02	3.37	80	60.7	33.4	50.1	16.7	0.4447	37.5
57	182508	77.5	0.86	4.75	74	53.2	33.3	47.6	14.3	0.432	33.1
58	81533	153	0.98	4.20	78	53.9	33.2	39.5	6.3	0.151	41.7
59	120863	108	0.94	4.67	77	59.1	33.4	43.7	10.3	0.270	38.2
60	141930	82.9	0.88	3.94	75	59.6	33.3	46.0	12.7	0.365	34.8
61	143958	108	1.00	5.22	79	61.7	33.1	47.2	14.1	0.365	38.6
62	206603	49.0	1.18	3.41	84	62.8	33.6	56.0	22.4	0.588	38.1
5	150170	89.0	1.89	4.50	100	88.1	72.1	84.0	11.9	0.554	21.5
6	167190	8.05	1.58	4.52	94	87.6	74.7	87.7	13.1	1.135	11 7
7	164945	78 3	1.37	4.35	89	85.5	72.5	85.0	12.5	1.703	7.91
8	161612	86.5	1.48	4.70	92	86.9	74.4	86.6	12.3	1.182	10.3
9	164458	79.0	1.74	4.36	97	87.8	72.8	86.3	13.5	0.815	15.6
10	185100	93.5	2.01	5.82	102	89.5	72.0	83.3	11.3	0.470	24.0
11	136850	94.5	2.00	4.35	102	87.3	72.4	83.5	11.1	0.470	23.6
12	192290	76.5	1.93	4.94	100	90.7	75.4	89.2	13.8	0.820	16.8
13	156470	96.0	1.94	5.06	100	88.2	72.8	83.8	11.0	0.519	21.2
14	176210	78.6	1.63	4.65	94	86.4	73.0	86.6	13.6	1.044	13.1
15	167103	69.0	2.41	3.88	107	91.8	78.2	93.5	15.3	0.751	20.4
16	167088	82.0	2.50	4.61	109	92.9	78.6	91.5	12.9	0.554	23.3
17	179170	81.0	2.30	4.86	106	86.4	73.6	86.7	13.1	0.519	25.3
18	149148	98.0.	2.27	4.92	106	89.7	72.8	83.6	10.8	0.382	27.5
19	201351	66.0	2.14	4.46	104	90.9	72.2	88.2	16.0	0.698	22.9
20	196680	51.0	2.17	3.37	104	90.3	73.6	93.7	21.1	1.105	19.1
21	144399	85.0	1.89	4.13	99	87.8	72.5	84.4	11.9	0.593	20.1
23	195514	75.5	2.20	4.95	105	91.1	73.0	87.0	14.0	0.571	24.5
24	173150	78.5	2.13	4.56	103	89.8	73.3	86.8	13.5	0.599	22.5
25	134635	101	2.14	4.56	104	88.8	72.3	82 8	10.5	0.399	26.3
26	161983	91.0	2.44	4.93	108	88.2	73.1	84.9	11.8	0.412	28.6

* Tests run on 59th Street exhaust turbine base condenser by H. G. Stott and R.J.S. P published in Trans. Am. Soc. M. E., vol. 32, p. 69.

TABLE 12 HEAT TRANSMISSION*

Series Number	Test Number	Steam Condensed Per Hour, Lb.	Ratio of Water to Steam, $\frac{Q}{W}$	Water Velocity, Ft. Per Sec.	Absolute Pressure, In. of Mercury	Steam Temperature, Deg. Fahr.	Hot-Well Temperature, Deg. Fahr.	Temperature of Inlet Water, Deg. Fahr.	Temperature of Outlet Water, Deg. Fahr.	Temperature Rise of Water, Deg. Fahr.	$\frac{t_s - t_0}{\text{Log}_e \frac{t_s - t_0}{t_s - t_1}}$	Mean Temperature Difference, Deg. Fahr.	B.t.u. Per Sq. Ft. Per Deg. Difference Per Hour.
		W	R	V_w	p	t_s	t_p	t_0	t_1	$t_1 - t_0$		θ	U
A†	987	1739	31.8	4.45	1.36	88.9	90.0	45.3	75.3	30.0	1.1663	25.7	646
	988	1992	28.2	4.52	1.63	94.7	92.4	45.2	79.0	33.8	1.1474	29.5	645
	989	1844	24.6	3.66	2.03	101.9	97.1	45.3	85.0	39.7	1.2090	32.8	549
	990	1986	17.7	2.85	2.46	108.4	112.0	45.5	101.0	55.5	2.1401	25.9	753
	991	1899	13.3	2.06	3.97	125.4	128.9	45.7	118.7	73.0	2.4759	29.5	623
	992	1781	8.5	1.24	11.94	169.2	171.6	46.0	161.7	115.7	2.7972	41.4	422
B	998	1121	49.2	6.38	0.80	72.6	72.2	46.0	66.7	20.7	1.504	13.15	829
	999	1101	41.1	5.20	0.80	72.6	75.1	46.0	70.5	24.5	2.53	9.68	1145
	1000	1073	34.5	4.23	0.90	76.2	79.5	46.2	75.8	29.6	4.32	6.86	1600
	1005	1517	24.2	4.21	1.41	90.1	95.4	46.5	89.8	43.3	4.98	8.69	1830
	1007	1400	11.6	1.82	5.36	136.6	138.6	47.5	135.6	88.5	4.48	19.6	729
	1008	1781	30.9	6.37	1.16	83.9	88.2	46.5	81.3	34.8	2.667	13.0	1465
	1009	1716	26.7	5.28	1.21	85.2	90.09	46.8	84.6	37.8	4.15	9.11	1905
	1010	1987	18.4	4.21	2.13	103.3	106.1	46.2	101.3	55.1	3.51	15.7	1283
	1011	1840	14.3	3.00	3.33	119.0	121.9	46.4	118.2	71.3	4.50	15.8	1184
C	1014	1265	45.9	4.56	1.03	80.2	76.3	46.0	68.0	22.0	1.0367	21.2	602
	1015	1302	35.9	3.66	1.03	80.2	79.9	46.0	72.5	26.5	1.4907	17.7	695
	1016	1194	30.7	2.85	1.18	84.4	86.2	46.1	78.7	32.6	1.9051	17.1	698
	1017	1191	22.3	2.04	1.55	93.1	95.3	46.3	88.3	42.0	2.2762	18.5	603
	1018	1170	13.8	1.22	3.93	125.0	123.5	46.9	119.7	72.8	2.686	27.1	433
	1031	1180	22.4	2.03	1.47	91.4	90.2	42.6	84.5	41.9	1.943	21.5	512
	1032	1148	51.5	4.65	0.95	77.8	76.5	42.0	60.8	18.8	0.7324	25.8	433
	1033	1681	35.3	4.66	0.98	78.7	77.5	42.0	68.5	26.5	1.2809	20.7	759
	1034	1570	16.8	2.04	2.56	110.0	109.7	42.5	102.0	59.5	2.1318	27.9	561
	1035	1848	14.2	2.03	3.48	120.5	121.9	42.5	114.0	71.5	2.4849	28.8	653
D	1055	2208	26.0	4.63	1.95	100.4	101.3	41.3	77.2	35.9	0.9322	38.5	865
	1056	2214	20.5	3.67	2.70	111.6	114.0	41.4	88.3	46.9	1.1019	42.7	806
	1057	2288	15.3	2.83	4.43	129.4	132.0	41.5	104.3	62.8	1.2528	50.1	705
	1058	1788	31.3	4.51	1.68	95.7	104.0	41.2	72.0	30.8	0.8329	37.1	753
	1059	1753	25.7	3.53	1.92	100.0	106.0	41.4	79.3	37.9	1.0403	36.4	757
	1060	1776	19.9	2.85	2.65	111.1	115.3	41.5	89.7	48.2	1.1787	40.9	672
	1061	1722	14.4	2.01	4.40	129.0	132.0	41.7	103.0	66.3	1.4255	46.6	570
E	1092	1157	47.6	6.48	0.98	76.8	75.0	43.5	61 8	18.3	0.7975	23.0	708
	1093	1105	32.1	4.17	1.13	83.1	81.7	44.1	72.5	28.4	1.3029	21.8	745
	1100	1649	33.6	6.47	0.90	76.1	78.7	40.0	62.6	22.6	0.9821	24.1	876
	1099	1646	22.1	4.17	1.40	90.0	94.0	40.0	82.0	42.0	2.1199	19.8	1242
	1098	1559	13.9	2.40	2.90	114.0	120.0	40.0	107.6	67.6	2.459	27.5	859
	1095	2191	25.7	6.52	1.43	90.5	88.0	40.0	76.2	36.2	1.2613	28.7	1145
	1096	2099	17.2	4.17	2.30	106.0	107.7	40.0	95.3	55.3	1.8197	30.4	1060
	1097	2010	10.4	2.39	5.70	139.0	142.0	40.3	129.7	85.4	2.3656	36.1	797

* Test made by R. L. Weighton and published in the Proc. Inst. Naval Arch., April 5, 1906.

† Series *A*—100 sq. ft. surface—Ordinary air pump. Tubes ¾ in. outside diameter, 16 ft. total length.
Series *B*—100 sq. ft. surface—Dry air pump-cores.
Series *C*—100 sq. ft. surface—Dry air pump.
Series *E*— 62 sq. ft. surface—Ordinary air pump. Tubes ¾ in. outside diameter, 10 ft. total length.
Series *F*— 62 sq. ft. surface—Dry air pump-cores.

TABLE 13 CONDENSER TESTS*

Test Number	Steam Condensed Per Hour, Lb.	Ratio of Water to Steam, $\frac{Q}{W}$	Average Velocity of Water, Ft. Per Sec.	Absolute Pressure in Condenser, In. of Mercury	Temperature of Steam, Deg. Fahr.	Hot-Well Temperature, Deg. Fahr.	Temperature of Inlet Water, Deg. Fahr.	Temperature End First Pass, Deg. Fahr.	Temperature End Second Pass, Deg. Fahr.	Temperature End Third Pass, Deg. Fahr.
	W	R	V_w	p	t_s	t_p	t_0	t_a	t_b	t_c
1	4000	51.4	See Table 13c	1.15	82.25	58.45	50.39	51.7	61.6	65.9
2	3985	34.6		1.39	90.0	68.9	50.42	52.6	69.9	75.35
3	4023	24.0		2.05	102.0	79.5	50.37	61.1	80.7	87.8
4	4050	18.73		2.79	113.0	89.6	50.4	65.4	90.5	99.0
5	2453	86.7		0.98	79.9	52.7	50.4	50.62	54.7	57.5
6	2427	49.8		1.06	81 9	54.0	50.4	50.93	60.4	65.8
7	2421	37.8		1.16	84.6	56.65	50.42	53.05	67.55	72.85
8	2421	30.15		1.42	90.0	65.65	50.42	56.57	73.9	79.35
9	2417	22.87		1.95	101.0	75.55	50.43	60.9	83.8	90.15
10	2457	16.7		3.05	115.5	93.0	50.45	67.6	99.15	106.5
101	12800	98		1.10	80.6	68.9	49.1			
102	7740	169		0.90	75.2	58.1	49.1			
103	1876	596		0.70	68.0	47.3	45.5			
111	154,400	21.1	7.52	5.27	133		59.2	73.4		
6-1	7665	32.6		1.55	93.2	65.85	50.76			
6-2	4837	43.1		0.93	80.6	57.2	50.76			
6-3	6250	38.4		1.11	84.25	62.42	50.76			
6-5	7685	32.1		1.98	102.05	79.17	50.76			
6-6	5890	40.4		1.49	93.55	71.08	50.76			
6-7	4750	44.1		1.30	90.95	68.6	50.76			
6-8	6070	41.9		1.40	92.15	70.0	50.76			
4-1	6870	39.2	1.275	1.15	82.3	64.4	50.55	61.1		
4-2	7018	28.5	0.945	1.52	92.3	69.1	50.55	68.6		
4-3	6890	23.1	0.719	2.04	102.3	77.7	50.71	79.5		
4-4	7133	17.4	0.588	2.87	114.1	87.5	50.55	93.8		
411	7133	36.9	1.246	2.16	104.2	87.3	71.9	88.3		
410	5760	46.0	1.256	1.67	95.6	80.8	70.2	82.5		
412	3898	67.3	1.241	1.32	88.9	77.7	71.6	79.0		
4-8	6865	24.9	0.810	1.79	97.9	71.4	50.55	75.6		
4-9	4542	38.0	0.816	1.12	81.9	62.8	50.55	63.35		
413	3221	54.5	0.829	0.80	72.7	58.1	50.36	55.5		
414	3182	82.3	1.239	0.65	66.6	54.5	50.36	51.1		
4-5	7200	19.6	0.668	2.48	108	82.7	50.55	85.15		
4-6	7050	19.9	0.663	2.93	114.1	69.7	50.55	62.41		
4-7	6975	20.2	0.668	3.40	119.8	61.2	50.55	54.05		

* Tests made by E. Josse and published in Zeitschrift des Vereines deutscher Ingenieure, February–March 1909.

† $\frac{l}{d}$ and U figured on inside diameter of tubes in all tests.

‡ Test 111 was on a turbine condenser with 6085 sq. ft. of surface, Number and size of tubes not given.

TABLE 13 CONDENSER TESTS—Con.

	Temperature Rise of Water, Deg. Fahr.	Mean Temperature Difference, Deg. Fahr.	Ratio Length in Ft. to Diameter in In.	B.t.u. Per Sq. Ft. Per Deg., Difference Per Hour	$\frac{t_2 - t_0}{\text{Log}_e \frac{t_2 - t_0}{t_2 - t_1}}$	
	$t_1 - t_0$	θ	$l \div d$	U		
3	20.84	19.60	23.6†	710	1.0613	
5	30.73	20.50	23.6	673	1.4974	
	43.73	23.3	23.6	590	1.8779	
	55.3	25.7	23.6	531	2.1494	Double condenser of 307 sq. ft. surface. Tubes 0.59 in. inside diameter in upper and 0.51 in. inside diameter in lower shell. 620 tubes. Length of water passage 13.93 ft.
7	11.97	23.1	23.6	359	0.5188	
	20.8	19.3	23.6	425	1.0791	
	27.48	16.9	23.6	485	1.6292	
	33.08	17.38	23.6	464	1.9559	
	45.37	19.95	23.6	408	2.2742	
	61.25	15.95	23.6	512	3.8396	
	10.8	25.8		280	0.4187	
	6.3	22.75		194	0.277	Surface 1883 sq. ft., size of tubes not reported.
	1.8	21.5		492	0.0839	
	44.3	48.3		490	0.9163	
0	32.94	22.0		388	1.497	
	24.66	14.1		378	1.748	
	27.66	15.85		435	1.746	Condenser of 959 sq. ft. surface. In tests 1-3 the tube contained spirals. Tests 5-8 had plain tubes.
	31.86	32.8		250	0.9708	
5	25.99	27.65		234	0.940	
5	24.39	26.15		203	0.9322	
	24.94	27.0		243	0.9243	
	27.25	13.95	21.3	553	1.953	
	37.75	16.1	21.3	488	2.344	
	48.09	17.89	21.3	431	2.689	
	59.55	21.5	21.3	395	2.766	
	29.0	12.7	21.3	630	2.281	
	22.2	9.59	21.3	640	2.318	Double condenser. Total surface 962 sq. ft. 688 tubes 708 in. inside diameter, 787 in. outside diameter, ¼ in. in each section. Area water pass 0.94 sq. ft. Total length water pass 15.08 ft.
	15.8	6.46	21.3	668	2.444	
	43.35	17.53	21.3	443	2.470	
	28.6	11.75	21.3	441	2.434	
	19.59	9.36	21.3	379	2.094	
	12.99	8.07	21.3	441	1.609	
	54.05	19.11	21.3	418	2.827	
	54.35	28.1	21.3	283	1.933	
	54.35	35.4	21.3	227	1.535	

TABLE 13a TESTS 1 TO 10

WATER VELOCITIES, FT. PER SEC.

No.		1	2	3	4	5	6	7	8	9	10
per denser	Upper Tubes	5.52	3.705	2.60	2.035	5.72	3.25	2.46	1.96	1.484	1.10
	Center (Cross) Tubes	2.54	1.71	1.194	0.94	2.63	1.50	1.135	0.907	0.684	0.51
	Lower Tubes	3.61	2.424	1.70	1.33	3.74	2.13	1.61	1.29	0.973	0.723
er Condenser		3.03	2.04	1.43	1.12	3.15	1.79	1.35	1.08	0.815	0.605

TABLE 14 HEAT TRANSMISSION TESTS *

MADE ON TUBE OF SHELBY COLD DRAWN STEEL, 1.253 IN. OUTSIDE DIAMETER, 0.995 IN. INSIDE DIAMETER, 6 FT. 7½ IN. LONG INSIDE CONDENSER†, $\frac{l}{d} = 5.27$, $S = 2.14$ SQ. FT.

Series Number	Test Number	Circulating Water Per Hour, Lb. Q	Ratio of Water to Steam, $\frac{Q}{W}$ R	Velocity of Water in Tube, Ft. Per Sec. V_w	Absolute Pressure in Condenser, Lb. Per Sq. In. p	Temperature of Steam, Deg. Fahr. t_s	Temperature of Inlet Water, Deg. Fahr. t_0	Temperature of Discharge Water, Deg. Fahr. t_1	Temperature Rise of Water, Deg. Fahr. $t_1 - t_0$	$\text{Log}_e \frac{t_s - t_0}{t_s - t_1}$	Mean Temperature Difference, Deg. Fahr. θ	B.t.u. Per Sq. Ft. Per Deg. Difference Per Hour U
A	1	19100	98.4	16.07	14.38	210.9	56.92	66.75	9.83	0.0888	148.9	[illegible]
	2	15800	80.2	13.29	14.38	210.9	58.20	70.25	12.05	0.0894	148.3	[illegible]
	3	14150	72.4	11.93	14.38	210.9	58.55	71.90	13.35	0.0915	148.0	[illegible]
	4	12250	66.4	10.33	14.38	210.9	58.63	73.20	14.57	0.1027	141.9	[illegible]
	5	10560	58.1	8.90	14.38	210.9	58.20	74.82	16.62	0.1142	146.0	[illegible]
	6	8820	55.6	7.43	14.38	210.9	57.89	75.28	17.39	0.1221	142.5	[illegible]
	7	7200	47.6	6.07	14.38	210.9	58.20	78.52	20.32	0.1434	142.6	[illegible]
	8	4860	36.9	4.11	14.38	210.9	58.29	84.49	26.20	0.1880	139.9	[illegible]
	9	3310	28.7	2.80	14.38	210.9	58.37	92.00	33.63	0.2483	135.6	[illegible]
	10	1740	19.5	1.48	14.38	210.9	58.91	108.4	49.50	0.3984	124.3	[illegible]
	11	427	8.38	0.37	14.38	210.9	60.10	175.5	115.4	1.4481	79.8	[illegible]
B	1	19900	62.3	16.78	44.49	273.6	58.55	73.35	14.80	0.0724	204.5	[illegible]
	2	14680	46.5	12.37	45.08	274.4	58.32	73.12	19.80	0.0962	205.9	[illegible]
	3	17670	53.3	14.89	44.56	273.7	58.15	75.45	17.30	0.0816	212.0	[illegible]
	4	12030	40.0	10.15	44.71	273.9	57.90	80.94	23.04	0.1123	205.0	[illegible]
	5	9350	33.2	7.89	44.85	274.1	58.03	85.83	27.80	0.1354	205.3	[illegible]
	6	6970	25.5	5.88	44.85	274.1	58.10	92.88	34.78	0.1757	198.0	[illegible]
	7	3458	16.0	2.94	44.85	274.1	62.87	120.46	57.59	0.3135	181.9	[illegible]
	8	4580	20.4	3.89	45.15	274.5	63.23	108.5	45.22	0.2388	189.5	[illegible]
	9	2141	11.2	1.84	45.15	274.5	63.73	145.9	82.17	0.4947	166.0	[illegible]
	10	1680	9.74	1.45	45.08	274.4	67.55	162.2	94.65	0.6114	155.0	[illegible]
C	1	20870	51.5	17.64	74.15	306.6	67.54	85.00	17.46	0.0770	227.0	[illegible]
	2	18400	45.7	15.50	74.15	306.6	67.54	87.19	19.65	0.0869	226.0	[illegible]
	3	13570	34.9	11.43	74.05	306.5	67.54	93.30	25.76	0.1142	226.0	[illegible]
	4	6280	18.3	5.33	74.37	306.8	58.73	107.7	48.96	0.2189	223.6	[illegible]
	5	4910	15.2	4.17	74.59	307.0	58.89	118.05	59.16	0.2715	218.0	[illegible]
	6	3720	12.7	3.17	74.59	307.0	59.27	129.7	70.43	0.3245	216.9	[illegible]
	7	2550	9.47	2.19	75.03	307.4	59.83	154.35	94.52	0.4289	197.0	[illegible]
D	1	20320	38.6	17.13	103.7	330.2	57.67	80.50	22.83	0.0971	235.0	[illegible]
	2	16630	33.7	14.05	103.4	330.0	57.67	83.26	26.21	0.1113	235.0	[illegible]
	3	12300	27.0	10.39	103.4	330.0	58.23	90.92	32.94	0.1394	236.0	[illegible]
	4	9530	22.2	8.06	103.7	330.2	58.17	97.90	39.73	0.1678	236.0	[illegible]
	5	5000	14.2	4.25	103.7	330.2	58.50	120.6	62.10	0.2586	240.0	[illegible]
	6	2680	8.60	2.31	103.7	330.2	58.89	161.5	102.61	0.4762	[illegible]	[illegible]

* Tests made by J. K. Clement and C. M. Garland and published in Bulletin 40 of the Univ[illegible] Illinois, September 27, 1909.

†The condenser was a specially designed apparatus for experimental work at the Engineering E[illegible] ment Station of the University of Illinois.

APPENDIX No. 2

REVIEW OF RESULTS OBTAINED BY DIFFERENT EXPERIMENTERS

CONDENSER TUBE EXPERIMENTS BY J. P. JOULE

Philosophical Transactions, Royal Society, Vol. 151, p. 133

43 The apparatus used in these tests consisted of a steam boiler, with a 1-in. pipe leading to a vertical condenser tube enclosed by a water pipe of slightly greater diameter. The steam was condensed in passing downward through the condenser tube, and the water of condensation ran out the bottom, where it was collected and weighed in a suitable tank. The cooling water was brought into the water jacket at either top or bottom and taken from the other end to another tank to be weighed. Thus, either counter-flow or parallel-flow was obtained, the cooling water passing through the annular space around the condenser tube while the steam passed on the inside of the tube. Suitable thermometers and mercury columns were provided to determine the temperature and pressure of the steam, the head on the circulating water, temperature rise of the water and the mean temperature difference.

44 The tubes used were of various sizes, thicknesses and materials and the water pipe also varied in size. For some tests helical channels were provided for the water by winding wire on the inner tube, giving the circulating water a whirling motion. The length of the tests varied from twenty minutes to an hour.

CONCLUSIONS

45 The following is a summary of his principal conclusions:

a The pressure in the vacuous space is sensibly equal in all parts.

b In the arrangement in which the steam is introduced into a tube whilst the refrigerating water is transmitted along a concentric space between the steam tube and a larger tube in which it is placed, it is a matter of indifference in which direction the water is transmitted, hence,

c The temperature of the vacuous space is sensibly equal in all parts.

d The resistance to conduction is to be attributed almost entirely to the film of water in immediate contact with the outside and inside surfaces of the tube and is little influenced by the kind of metal of which the tube is composed, or by its thickness in the limits of ordinary tubes, or even by the state of its surface as to greasiness or oxidation.

e The narrowing of the steam space by placing a rod in the axis of the steam tube does not produce any sensible effect.

f The conductivity increases as the rapidity of the stream of water is augmented. In the circumstances of my experiments, the conduction was nearly proportional to the cube root of the velocity of the water; but at very low velocities it evidently increases more rapidly than according to this law, whilst at very high velocities it increases less and less rapidly as it gradually approaches a limit determined by the resistance of the metal and of the film of water adhering to the inside surface of the tube.

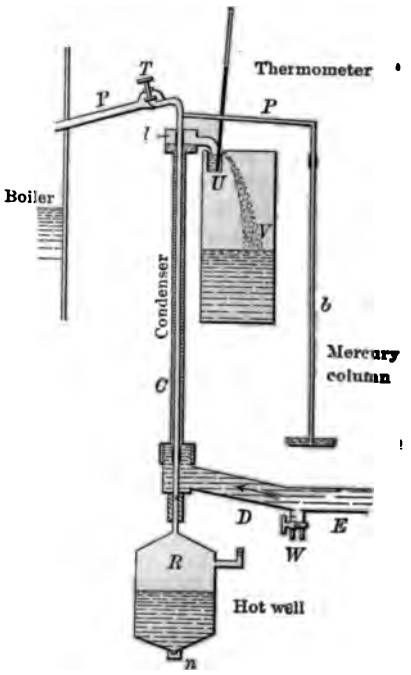


FIG. 12 JOULE'S APPARATUS

g The conductivity increases so slowly in relation to the height of the head of water, that the limit to the economical increase of the latter is soon attained.

h By means of a contrivance for the automatical agitation of the particles of the refrigerating stream, such as the spirals I have employed, an improvement in the conductivity for a given head of water is obtained.

i The total heat of steam above 0 deg. cent. determined by the average of 151 experiments, is 644.28 heat units for a pressure of 47.962 in.

EXPERIMENTS ON SURFACE CONDENSATION

Abstract of a Paper by James Alexander Smith, Read Before the Victorian Institute of Engineers, December 6, 1905

Engineering, Vol. 81, p. 395

46 This paper is a sequel to a former paper on Air in Relation to Boiler Feed, Engineering, October 7, 1904.

47 The preliminary experiments were made with closed glass tubes containing bromine both with and without air in the vapor space. The low boiling point,

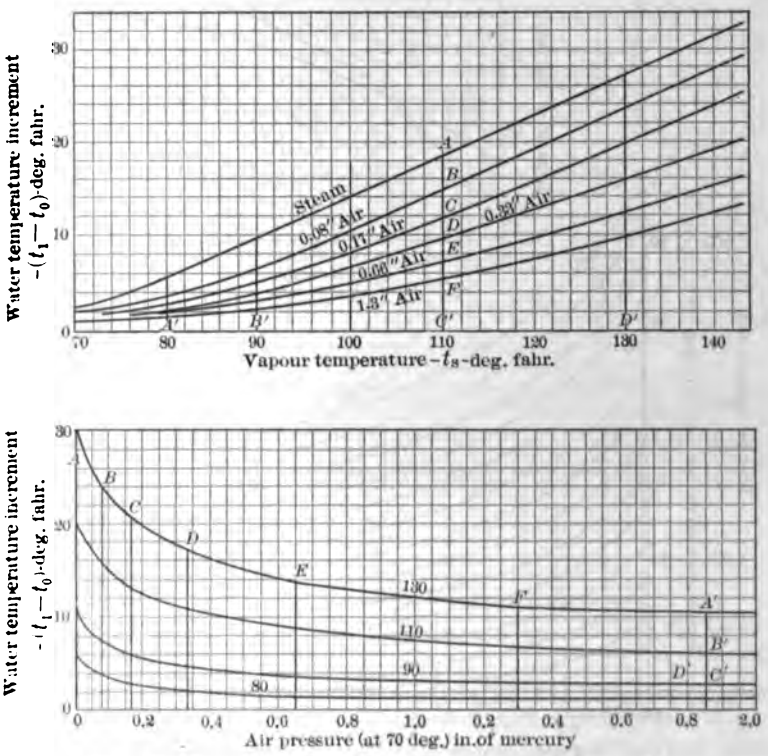


Fig. 13 Variation of Heat Transmission with Air

deep non-actinic color of the vapor and strong russet red of the condensed films made the processes of diffusion and condensation easy to follow. The final apparatus consisted of a boiler 3 ft. long, 7½ in. in diameter, made of No. 19 B.w.g. galvanized sheet steel with joints folded, soldered and tarred. The leakage was only sufficient to reduce the mercury gage level $\frac{1}{20}$ in. in 24 hours. The boiler was heated externally by 60 gas jets each ¼ in. in diameter.

The boiler was provided with glass windows for observation of the int and the standard mercury columns, thermometers, etc. The condensing were in two lengths about 3 ft. long, making an effective length of ab ft. The external surface exposed to the vapor was exactly 1 sq. ft., ext diameter of the tubes about $\frac{3}{4}$ in. thickness 0.018 in., sectional area of the i tube 0.26 sq. in. Tubes were hard drawn brass.

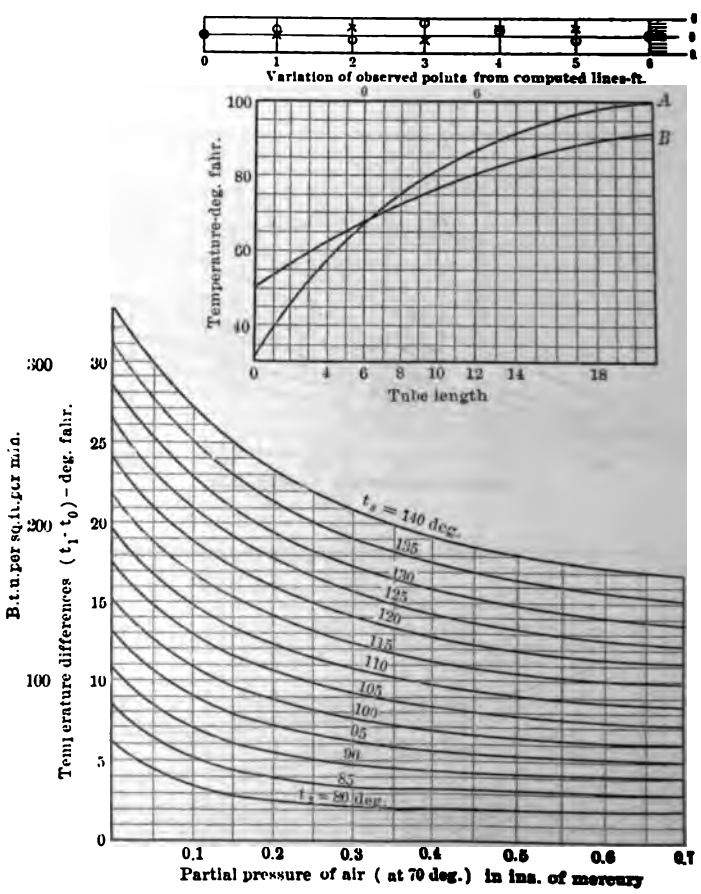


FIG. 14 VARIATION OF HEAT TRANSMISSION WITH AIR

48 Constant-flow apparatus was provided for the condensing water various quantities from 2½ lb. to 20 lb. per min. could be passed thro tube. Apparatus was provided whereby, after the boiler was freed fro known amount of air at a noted pressure and temperature could be adde contents of the boiler.

TESTS

49 A series of tests was run to determine the effect of air admixture. Air-free steam was condensed at vacua varying from 70 deg. to 140 deg. at 10 deg. intervals. Air was then added in varying quantities and the process repeated. Another set of tests was made in which the condenser was maintained at constant temperature, while air in the mixture was varied at definite intervals. In both series the cooling water flowed at the constant rate of 10

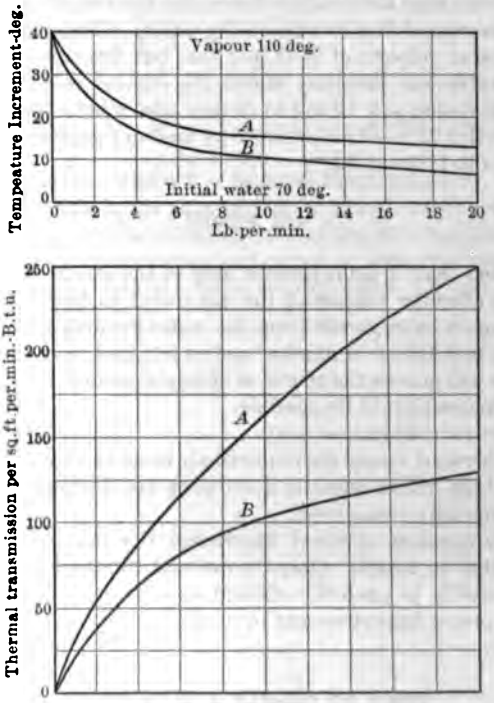


FIG. 15 VARIATION OF HEAT TRANSMISSION WITH WATER VELOCITY

lb. per min. and the cooling surface was 1 sq. ft. From these experiments it was determined that with constant flow and surface and air-free steam the temperature increment of the cooling water is in a constant ratio to the temperature increment of the steam, at least to a first approximation.

50 The presence of air in the condenser, equal in pressure to $\frac{1}{20}$ in. of mercury will at 90 deg. fahr. reduce thermal transmission about 25 per cent, while $\frac{1}{10}$ in. of mercury of air pressure will reduce the thermal transmission by one-half.

Corollary 1 The rise in water temperature is proportional to the initial steam and water differences of temperatures.

Corollary 2 Each decrement of condenser temperature requires a proportional increment of cooling surface, provided the tube length is constant.

51 Experiments were made to determine the law of the rise of temperat of the cooling water in the tube, and points were taken 1 ft. apart in the t of length of tube, making seven points in all. The temperatures observed these points under various conditions were plotted and found to lie alon exponential curve, the observed points varying no more than 0.4 of one de from the calculated curve. When air was admitted to the steam the curve considerably flatter than with air-free steam. From this it is deduced t economy requires the use of relatively short tubes.

52 Experiments were also made to determine the variation of the heat tr mission with the rate of flow of the cooling water. These experiments did go beyond a water velocity of 2½ ft. per sec., but the tubes were small an all cases the water was probably above the critical velocity. With air- steam the transmission at 5, 10 and 15 lb. per min. was in the ratio of 1 to to 2.10, while with 2.22 in. of air pressure by mercury gage with the same f the ratios were 1 to 1.31 to 1.52.

AIR PUMPS

53 It is stated that if air is present only to the extent of $\frac{1}{10}$ in. of mer the ratio of the effective volume of the air pump to boiler feed is 20 t The air pump must be separate from the water-removing pump. Air p inlets should be multiplied in number and so situated that the concentra air in the vapor will pursue the course of shortest contact with the cooling face; no dead spaces should be possible.

54 The author's conclusions are:

a If high vapor vacua are required air must be excluded.

b With high vacua climatic conditions are limiting factors and r be specially considered.

c In the absence of exact knowledge the impossible has been tempted in design. Only by rational condenser proportion wi be possible to push the efficient expansion of steam to those li that recent improvements in motors seem to render easy of att ment.

TESTS BY GUSTAV A. HAGEMANN

Proceedings of the Institution of Civil Engineers, Vol. 77. p. 311, 18

55 The author refers (page 311) to experiments of Messrs. Easton and A of London as the only ones published. These were made on a perpendicular tube $\frac{1}{16}$ in. thick and 1½ in. in diameter, which was enclosed in a larger tu in. in diameter, containing water. Dry steam of known temperature was led the inner pipe and the amount of steam condensed and the rise of temperi of water was measured. By means of this apparatus a temperature differe 69.5 deg. cent. gave a heat transmission of 15.3 units of heat per unit of

56 The author used an improved apparatus as follows: A brass tube 0 in. thick and 1.93 in. outside diameter and 37 in. long, giving a heating su of 1.56 sq. ft., was fitted steam tight in the center of a strong cast-iron about 6 in. inside diameter, the lower end of the brass tube being connect

a pipe with a tank which contained a copper steam coil whereby the water in the tank could be raised to any desired temperature. The other end of the tube connected to a vessel on a scale. The iron pipe was provided with steam through a smaller pipe tapped into it.

$$t_s - \frac{(t_1 + t_0)}{2} = \text{temperature difference, deg. cent.}$$

t_s being steam temperature and t_1 and t_0 water temperature. If A is weight of water passing in B minutes, $\frac{A}{B}(t_0 - t_1)$ = units of heat transmitted per min. in lb., deg. cent.

$$\frac{2A\ (t_0 - t_1)}{BS\ [2t_s - (t_0 - t_1)\ ]} = \text{units of heat transmitted per sq. ft.}$$

per deg. cent. per min., where S = internal heating surface.

57 After a few tests the space between the inner and outer tubes was found to be too great giving large variations in the temperature readings; accordingly, a tube 1.515 in. in outside diameter, and closed at both ends was placed in the heating tubes, thus reducing the space for the water to pass to an annular area 0.1305 in. in width.

APPENDIX No. 3

REFERENCES TO TRANSMISSION OF HEAT THROUGH TUI PARTICULARLY AS APPLIED TO SURFACE CONDENSATIOI

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1860 Wye Williams. Heat and its Relation to Steam and Water. *Lon*

1861 Joule. Experiments on Transmission of Heat: (1) Steam to Air. Steam to Water. Phil. Trans. Royal Soc., Vol. 151, p.

1871 Burgh. Practical Treatise on the Condensation of Steam.

1873 Rankine. The Steam Engine.

1875 B. G. Nichols. Effect of Velocity of Water in Surface Steam Cond ing. Engineering, Vol. 20, p. 449.

1880 Sir William Thomson (Lord Kelvin). Article on Heat. Encycl. B 9th edit., p. 577.

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1887 Ser. Traite de Physique Industrie. *Paris.* Vol. 1 and 2, p. 225.

1887 Reynolds. Effect of the Presence of Air on the Heat Transmi Power of Steam. Zeitschrift des Vereines deutscher I nieure, Vol. 31, p. 284.

1888 Lang. On Evaporation. Trans. Inst. Engrs. and Shipbuilders of S land, Vol. 32, p. 279.

1894 Preston. Theory of Heat.

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1895 Editorial. Transmission of Heat through Boiler Plates. Engrg. ord, Vol. 32, p. 192.

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1904 Hausbrand. Evaporation, Condensation and Cooling. Scott, Greenwood & Co., *London*.
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1905 Allen. Surface Condensing Plants and the Value of the Vacuum Produced. Proc. Inst. C. E., Vol. 161, p. 169.
1906 Weighton. The Efficiency of Surface Condensers. Trans. Inst. Naval Arch., Vol. 48, p. 123.
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1907 Tansley. The Heating of Air by Flue Gases. Proc. Inst. C. E., Vol. 171, p. 371.
1908 McBride. Air Leakage in Steam Condensers. Proc. Am. Soc. M. E., June 1908, p. 797.
1908 Morison. Steam Condensing Plant for Cargo Steamers. Cassiers, vol. 35, p. 208.
1908 Morison. The Influence of Air on Vacuum in Surface Condensers. Trans. Inst. Naval Arch., Vol. 50, p. 150.
1909 Josse. Test of Surface Condensers in Connection with Steam Turbines. Zeitschrift des Vereines deutscher Ingenieure, Vol. 53, pp. 322 and 406.
1909 Clement and Garland. The Transmission of Heat to Water in Tubes as Affected by the Velocity of the Water. Univ. of Ill. Bulletin 40, 1909.
1909 Dalby. Heat Transmission. Engineering (London), Vol. 88, p. 560.
1909 Dalby. Discussion on paper Heat Transmission. Engineering (London), Vol. 88, p. 539.
1909 Wright. The Design of Condensing Plant.
1909 Jordan. Discussion on paper Heat Transmission. Engineering (London), Vol. 88, p. 541.
1909 Neilson. The Transmission of Heat between Fluids. Engineer, Vol. 107, p. 157.
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1910 Editorial. A Study in Heat Transmission. Engineer, Vol. 110, p. 14.

DISCUSSION

W. D. ENNIS. Perhaps the exact variation of the coefficient U in relation to the mean temperature difference is a little surprising. The figures given in Par. 41 under item e are of particular value. These rates of transmission are, of course, based on outside tube surface. I wish that a little discussion had been included in the paper on the question of tube thickness, and two or three other practical questions. Take the matter of oxidation. Mr. Orrok lays some stress on oxidation as a determining factor, although Joule regarded it as of slight influence. The question is both technical and commercial at this point. We have oxidation on the one hand, and the transmissive coefficient on the other, and in addition a large number of purely commercial factors. The question of an oil coating in reciprocating engine installations would be one of the factors presumably taken care of by the cleanliness coefficient c, but for this we have no data in the paper. I should like to know what kind of tube Mr. Orrok uses in his own practice here in New York with salt water for condensing.

As to the irregularity in individual figures, there is no question but that the general laws and the general form of the final equation are thoroughly demonstrated by the tests. The families of points are clearly defined, but when we take any one curve, such as the water velocity curve, we find that these points are rather widely scattered about the curve itself. The curves in Fig. 9 show a little more scattering than should be expected in a determination of this kind. I believe Mr. Orrok attributes this to air. I cannot see why, under these conditions, with a closed cycle and a fairly constant vacuum for a given set of tests, the air should vary a great deal. If it does vary as much as some of the figures given in Par. 38 appear to indicate, on what basis or in what way was that amount of variation determined, and can it be shown that the variation in air is related to the variation in individual points over the curve? There seems to be evidence of some error on comparing the positions of points with the position of the smooth curve. I think the water meter is entirely satisfactory for measuring water velocity, but in using

the meter as an element in getting at heat measurement, I should prefer to have it checked by means of water weights.

Finally, in the formula bearing on water velocity, $U = m\sqrt{V}$, which is mentioned in various places, I find two interesting things: First, Mr. Orrok's value for the constant m is very nearly the arithmetical mean of all the values obtained by all the other observers who take U as proportional to the square root of V. There should be some reason for that. The other determinations I have not had time to examine in detail, but we would expect to find something in the manipulation to account for the variations in one direction in some cases and in the other direction in other cases. Again, if we take the results in Fig. 6, where conductivity is determined in relation to temperature difference, we find the four values of the constant to be 370, 416, 433 and 410. It would seem as if there should be a better agreement with the value 308, directly obtained.

This is certainly a noteworthy paper. It represents the analysis of a problem that is essentially commercial, perhaps, in a most thorough and painstaking way. I should like to ask Mr. Orrok how the rate of flow in the apparatus compared with that in a modern large surface condenser. The paper is very full of detail and I may have overlooked the information.

WILLIAM KENT. I would suggest to Mr. Orrok that he supplement his paper with another one in which he will give formulae to show how many square feet of surface should be put into a condenser to condense 1000 lb. of steam at the vacua of 27, 28 and 29 in., with initial temperatures of 50, 60 and 70 and with the final temperature of water 5, 10 and 15 deg. below the temperature of the steam. What we need are formulae which designers can use.

H. H. SUPLEE. Mr. Orrok has called attention to the important influence of the presence of air in condensers, and in this connection he has quoted the paper[1] of D. B. Morison, who in this and other papers, has called attention to the fact that it is not only the presence, but also the location of air which measures its hurtfulness to the efficiency of the condenser. The tendency of air which comes in through leaks is simply to crowd out steam and impair the vacuum. Air which is combined with the steam, and carried in with it, how-

[1] The Influence of Air on Vacuum in Surface Condensers, Trans. Inst. Naval Arch., vol. 50, 1908, p. 150.

ever, is carried directly to the surface of the tubes, since the vacuum is formed at the point of condensation and the incoming steam rushes directly to the coldest surfaces, carrying with it the contained air. Since this air is not condensed, it remains in close contact with the tubes, probably in the form of minute bubbles, forming a blanket or jacket of non-conducting character, and thus reduces very materially the condensing value of the cooling surface of the tubes. Air in such a location is more harmful than that which leaks in directly and acts principally by displacement. It has been suggested that if the tubes of the condenser were fitted with moving scrapers, similar to those used on economizers employed for heating boiler-feed water, this non-conducting jacket of air would be scraped off, and the efficiency greatly increased. Until something is done to meet this condition it seems as if determinations of heat transfer in surface condensers are almost certain to be irregular and inconsistent.

THOS. C. MCBRIDE. The writer is particularly interested in the author's experience as to the effect of air mixed with the steam, as stated in Par. 39, and the fact that this air, apparently from an unknown cause, varied in amount so greatly in the apparatus as first constructed and connected that the results did not seem to be constant enough to have any scientific value. The conditions of these first tests were apparently, however, those which we meet in low-pressure turbine practice, and it seems to the writer, therefore, that they should have a practical value. It is hoped that the author will explain more fully the origin of the exhaust steam used in the apparatus as first constructed, and his conclusion as to what might have been expected from it as revealed by his tests, if used on low-pressure turbine work.

In all tests of the kind conducted by the author, the amount of air and non-condensable vapors present in the steam must necessarily introduce an element of doubt as to the results, and the presence of this element of doubt in the author's mind is shown in his statement in Par. 39. The author does not state how he arrived at the conclusion that there was not more than $\frac{1}{4}$ in. of air pressure in the steam nor has he commented on any comparison of his statement with Mr. Smith's conclusions as stated in Pars. 40, 50 and 53, the latter stating that if air is present to the extent of $\frac{1}{20}$ in. of mercury the ratio of effective volume of the air pump to boiler-feed pump is 20 to 1.

If, as the author states in Par. 39, the partial air pressure in his apparatus approached $\frac{1}{4}$ in. of mercury, the results obtained can

hardly be considered as applying to practical conditions in surface condensers. In the writer's opinion, the heat transfer results obtained indicate very much less air, this opinion being based on the heat transfer results obtained and air condition existing in surface condenser plants. Any condenser having as much as $\frac{1}{4}$ in. of air pressure would require a vacuum pump of a size that would be prohibitive. As an example, if we assume the condition usually existing in surface condensers carrying 26 in. of vacuum, where it is presumed that the temperature of the water, steam and air passing to the vacuum pump is 110 deg., one volume of air at its individual pressure of $\frac{1}{4}$ in. and temperature of 123 deg., to which the steam temperature has been reduced by its presence, will become after passing through the condenser at its temperature of 110 deg. and individual pressure of 1.4 in.

$$\frac{0.25}{1.40} \times \frac{459.5 + 110}{459.5 + 123} = 0.174 \text{ vol.}$$

Similarly this one volume of steam at its individual pressure of $3\frac{3}{4}$ in. before reaching the condenser has a volume 11,687 times that of the corresponding water. The ratio of the effective displacement of the air pump and the boiler-feed pump required to handle this air will be

$$\frac{0.174}{\frac{1}{11{,}687}} = 2060$$

The usual practice of manufacturers for these conditions is an air pump ratio of about 13 to 1.

Similarly, assuming $\frac{1}{4}$ in. of air pressure in the exhaust steam with 28 in. of vacuum in the steam turbine work and that a separate cooler and rotative dry vacuum pump are used, assuming also that the mixture of air and steam pass from the condenser to the rotative dry vacuum pump at a temperature of 75 deg., one volume of air as it exists in the exhaust pipe at its individual pressure of $\frac{1}{4}$ in. and its temperature of 97 deg., will have after leaving the condenser an individual pressure of 1.13 in. and a temperature of 75 deg. and therefore become

$$\frac{0.25}{1.13} \times \frac{459.5 + 75}{459.5 + 97} = 0.212 \text{ vol.}$$

The volume of steam in the exhaust pipe at its individual pressure of $1\frac{3}{4}$ in. will in its condensation be reduced in volume about 23,875 times, or the ratio of the effective displacement of the rotative dry vacuum pump to the boiler-feed pump must be

$$\frac{\frac{212}{1}}{23{,}875} = 5060$$

This again is prohibitive representing a vacuum displacement 200 or 300 times that usually found necessary in steam turbine condenser work.

Accepting Mr. Smith's statement that the effective displacement of the rotative dry vacuum pump must be about 20 times the displacement of the feed pump, we can calculate the amount of air presupposed by this statement to be mixed with the steam on its way to the condenser. Using the same assumptions as above for 28 in. of vacuum, one volume of water in the feed pump becomes about 21,500 volumes on its way to the condenser. Twenty volumes of air passing from the condenser to the rotative dry vacuum pump at its temperature of 75 deg. and individual pressure of 1.13 in. would have, when mixed with the steam before condensation, a volume of 21,500 and a temperature practically of 101.4 deg. Neglecting the slight increase in volume by change of temperature the inches of individual pressure of this air in the exhaust pipe must then have been

$$\frac{20}{21{,}500} \times 1.13 = 0.00105 \text{ in.}$$

The relative volumes of the air and steam in the exhaust pipe, if separated, would therefore be as 0.00105 to 2, or a ratio of 0.00052. In other words, Mr. Smith's conclusions as to the rotative dry vacuum pump capacity that should be used involve 5.2 volumes of air mixed with 10,000 volumes of steam in the pipe leading to the condenser.

This value corresponds very closely to the values of 4, 6.3 and 4.1 volumes of air per 10,000 volumes of exhaust steam stated in Par. 15 of the writer's paper, Air Leakage in Steam Condensers[1], presented before the Society at the Detroit meeting, June 1908.

[1] Proc. Am. Soc. M. E., June 1908, p. 797.

It is for the above reasons that the writer concludes that the air mixed with the steam in the author's apparatus was present in very much smaller volumes than the author has supposed.

It is interesting to note that the author proposes to undertake some measurements of dry air pump discharge. The writer does not know of any data having been published concerning this feature of condenser work, although Mr. Morison seems to have made a study of the subject as set forth in the paper which the author has quoted.

These questions suggest the advisability of the Society's adopting some sort of a standard code or standard method of testing large condensers, particularly as refers to the question of the amount of air present and the influence of this air on the results obtained, and it is believed by the writer that much useful work could be accomplished by the Society in establishing some such code.

R. M. NEILSON. In Par. 25, Mr. Orrok says: "The quantities of cooling water were so large that the temperature rise $(t_0 - t_1)$ was always small, and it was considered that the arithmetical mean of the water temperatures and the steam temperature might be used without appreciable error in the calculation of the heat transfer." This assumption may have been quite justified in the experiments in question, but I would like to point out for the benefit of future experimenters that the assumption is not necessarily justifiable on the ground that the water temperature rise is small. If there is much air in the steam admitted to the condenser, the steam temperature within the condenser is not constant, but falls as the steam is condensed and consequently the steam-air mixture becomes continually richer in air.

Regarding Mr. Orrok's conclusions on the effect of water velocity on the heat-transfer rate, I do not think that there is any scientific reason why the rate of heat transfer should vary as the square root of the velocity. I quite agree that for a limited length the curve approximately agrees with the formula $V = C\sqrt{V_w}$, but I am convinced that this is so only for a limited length. In Fig. 9 it can be seen that the lower curve begins to fail towards its upper end at a velocity of about 8 ft. per sec. The second curve can be seen to fail at its lower end. If Mr. Orrok will make further experiments and plot curves to a large scale with a range of water velocities from 0.25 ft. per sec. up to 3 ft. per sec., he will find, I am convinced, that no square-root curve will agree with the curves of actual results. Moreover, if he will plot further curves for data obtained with high

water velocities and large amounts of air, and other curves again for data obtained with high water velocities and dirty tubes, he will find that U will vary approximately and for a limited range with a power of the velocity whose index is clearly much less than 0.5.

Mr. Orrok's conclusion that the rate of heat transmission is independent of the velocity of the steam among the tubes of a surface condenser, is not, I think, generally correct although it may be nearly correct when the steam is airless. When air is present in the steam steam velocity has an influence. It may quite reasonably be that high steam velocity tangential to (as opposed to normal to) the tube surface assists in sweeping away the air which will naturally tend, owing to the condensation of the steam, to collect in the vicinity of the tube surface.

As it is desirable that the same symbols should as far as possible be used by different parties, I would suggest that k be used universally as the heat transmission coefficient instead of U used by Mr. Orrok. In Europe k has come into general use and it cannot now very well be replaced by another letter.

As regards Hagemann's tests referred to by Mr. Orrok, it may be well to point out that there appears to be a serious mistake in the second diagram in Hagemann's paper which causes it to be misleading. In this diagram all the curves are made to pass through the intersections of the principal coördinates, whereas there appears to be no ground either scientific or experimental, for such an assumption.

Most of the points treated by Mr. Orrok are also dealt with in the paper[1] which I read before the Institution of Engineers and Shipbuilders in Scotland and in the discussion which followed the reading of the paper. I think that those interested in the subject of surface condensation would find it of advantage to read the discussion which followed the reading of this paper.

THE AUTHOR. The subject of condensers and condensation has interested me for many years, and I have looked at it both from the practical standpoint in the transaction of my ordinary engineering work and also somewhat from the theoretical side. Ten years ago, while working on the design of what was at that time one of the largest condensers then contemplated, I tried to find out what other people knew about condensers and see whether there was any literature extant which told anything about it.

[1] The Design of Surface Condensers by R. M. Neilson, Trans. Inst. Engineers and Shipbuilders in Scotland, February 1910.

I greatly regret that it has been impossible for me to get the electric couples for attachment to the condenser tube to determine the rise in temperature of the condensing water. To do this as it should be done, a tube of at least 12 ft. to 16 ft. in length would be required with an electric couple every foot. Then we could search out and determine what that law actually is, and I believe it will be found to be the same in all cases. All of the experiments I have seen or heard of and those we have made ourselves indicate this result.

One or two members have written me regarding some of the mathematics, and apparently are troubled by the distinction I have drawn between N, the total heat transmitted, and U, the coefficient of heat transmission. I think after they study the tables a little this difficulty will disappear. I had to make some such supposition or distinction, or I could not have gone ahead with the mathematical discussion.

In answer to Professor Ennis's question, I think we kept within the condenser limits, that is, I went as high as 10 or 11 ft. per sec., and went down as low a 1 ft. per sec.; that is, all of the experiments are within the condensing range. We did run one set of experiments at 4 in. or 5 in. of vacuum, and succeeded in condensing 220 lb. of steam per sq. ft. of surface, and I think that is double what has been done before, but so far as the conditions are concerned, they are within condenser practice.

Professor Ennis speaks about the thickness of the tube. Most of the tubes which we tested were of the same thickness, 18 gage; I had some 16 and some 20. I could not determine any difference between 16, 18 and 20-gage tubes. In fact, my own idea is that I do not think I could have detected much difference between 14 and 20, and perhaps even larger. I think we never used a tube up to the limit of its capacity.

Regarding the oxidation problem, I suppose we tested 15 or 20 tubes in various stages of oxidation. The two lower curves in Fig. 9 represent a new Admiralty tube, that is, the one that $U = 308$, and the one below, at 224, an old Admiralty tube that had been oxidized. I would not like to state how much it was oxidized. I am not at all ready to state that that law is exactly the square root—it might be the cube or some other fractional power. It is in that neighborhood. If one were to plot every heat transmission experiment and then try to draw a mean through the center of these points, one would probably get somewhere within 0.05 on either side of the one-half, that is, it would go from 0.45 to 0.55 for the exponent.

Professor Ennis thinks my variation there is quite large. I acknowledge it is large, but it is less than we were able to get in any other way, and I hope some day to make it smaller yet, but at present do not see my way to do it. I have no doubt that by means of the galvanized iron boiler sealed up, using the boiler as a condenser and knowing absolutely that he had no air in it, Professor Smith's results, if we had them, would be better than mine. Evidently he did not publish his data, that is, not in the detail necessary for such calculation, and all we can take are his curves.

Mr. McBride wishes to know where our exhaust steam came from. This is the exhaust steam from blower engines and such auxiliaries turned into a large main running the length of the station, and discharging into open heaters. The chances for air are large, and I have no doubt there was air. Why do I say $\frac{1}{4}$ in. of partial pressure at the worst? That is an estimate. I tried thermometers and pressure gages and almost every other means at my disposal to tell how much air I had, and while I could be sure of it for one minute, I could not be certain of it for more. I found by reading Professor Smith's paper that he had exactly the same condition, and worked six months to get the galvanized iron tank tight, and after he soldered the edges and tarred them, he found the soldered tank would not hold tight and the air would get in. In our case the so-called boiler was made of a couple of 14-in. 200-lb. steel tees. I have no doubt air came through the pores of that steel at a greater or less degree at that vacuum. As to the pipe that I used for the condenser and the connections, I have no doubt that this leaked air under vacuum conditions. I had two 1-in. air lines running to a big dry vacuum pump and a condenser and I was pretty certain of the flow of steam through the pipe, so that there was a continual current parallel with the tube to sweep that air out of the condenser, and even then I think I had air. We tried to find whether there was any variation of temperature within that 5-in. tube that was the shell of the condenser. We put thermometers in it and raised them up and down and put them close to the tube and close to the edges, and at three points along the length, and we could not find any difference in temperature any larger than about one-tenth of a degree. Now I have found very much greater differences on a big condenser, but I think in the tube space, where the steam is, you can nearly always find practically the same temperature.

I hope that somebody will find some other tests. I am pretty certain there are others than those I have read, and I would like to know of them if any one finds them.

Regarding the discussion by R. M. Neilson, his point that the use of the arithmetical mean of the water and steam temperatures could not be used without appreciable error in other cases, is justified. In this particular case, the differences were so small as to make practically no difference in the plot; I have had them recalculated to be certain about it.

His point regarding the rate of heat transfer varying with the water velocity has been amply covered in the discussion. There are certainly three ranges to this curve, the first up to about 1 ft. or 1½ ft. per sec., where in some cases, the water would be below its critical velocity and the curve would be much steeper; the main case, where the slope is approximately the square root; the third case, above 7 ft. or 8 ft. per sec., where the curve flattens out rather more than it should to fill the square-root law. I am not at all certain that it will ever be possible to find a law which will be true for all conditions, but within the limits of practical designing the square-root law seems to be close enough.

Professor Kent has asked me to furnish the mathematics for the derivation of all of the formulae given in Tables 1–14. The following will, I think, be sufficient for this purpose. In order to show the relations of the total heat transmitted, the coefficient of the heat transmission and the mean temperature difference in a little better shape, I have had the diagrams (Fig. 16) drawn which will tend to give a better understanding of the mathematics involved.

Let N be the total heat transmitted per square foot of surface and U the coefficient of heat transmission, then $N = U\theta$ where θ = temperature difference. When U is constant throughout the surface of the condenser, θ will be the true mean ordinate of the curve of temperature rise. When U is not constant but varies according to some law, θ will not be the true mean ordinate, but will be greater than the mean ordinate when U is larger proportionately at the beginning of the water flow and smaller when U is proportionately larger at the end of the water travel. U must be a mean value for the whole condenser, since it must be assumed in designing. θ can always be calculated when the law of the variation of U is known.

Let Q be the weight of the circulating water per hour, $(t_1 - t_0)$ the rise in temperature in passing through the condenser and S the total surface in square feet. Then

$$\frac{Q\,(t_1 - t_0)}{S} = N = U\theta \text{ and } S = \frac{Q\,(t_1 - t_0)}{U\theta}$$

Now the law of temperature rise in the tube is not known. Two sets of tests to determine this law have been made and apparently this law is U = a constant, or $U = \frac{K}{\theta^0}$.

No numbers have been given, however, and U may vary within narro limits. From my own tests based on values of U and θ I find the relatio $U = \frac{K}{\theta^{\frac{1}{4}}}$. This, however, is not nearly so good as to measure the rise of t

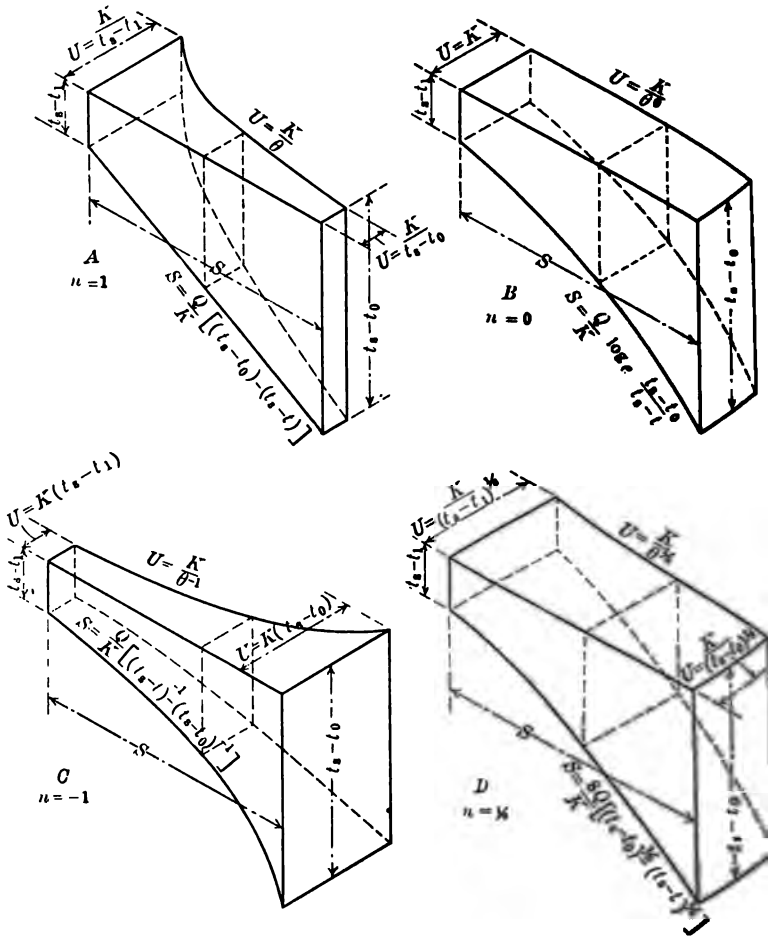


FIG. 16 DIAGRAMS SHOWING HEAT TRANSMISSION IN CONDENSERS

water temperature directly as did Smith and Josse and the values of θ the arithmetical mean and not the logarithmic mean, although this for temperature ranges should make little difference.

Now suppose U to vary as $\frac{K}{\theta^n}$ or $U = \frac{K}{\theta^n}$, then N is equal to $\frac{\theta K}{\theta^n}$ or $N =$

The rate of temperature rise in the water is

$$\frac{dt}{ds} = \frac{U\theta}{Q} \text{ and } ds = \int \frac{Q\,dt}{U\theta} = \int \frac{Q\,dt}{\frac{K}{\theta^n}\theta} = \int \frac{Q\,dt}{K\theta^{1-n}}$$

Now

$$\theta = t_s - t$$

$$ds = \int \frac{Q\,dt}{K\,(t_s - t)^{1-n}}$$

$$= \frac{Q}{K}\int_{t_0}^{t_1} \frac{dt}{(t_s - t)^{1-n}}$$

Now integrating between the limits t_0 and t_1 we get

$$S = \frac{Q}{K}\left[(t_s - t_0)^n - (t_s - t_1)^n\right]$$

When n is taken as O the above integration fails and the equation takes the logarithmic form

$$S = \frac{Q}{K}\log_e \frac{t_s - t_0}{t_s - t_1} \text{ (See Case 2)}$$

Now

$$\theta = \frac{Q\,(t_1 - t_0)}{SU},\ U = \frac{K}{\theta^n} \text{ and } S = \frac{Q}{K}\left[(t_s - t_0)^n - (t_s - t_1)^n\right]$$

Substituting we get

$$\theta = \left[\frac{n\,(t_1 - t_0)}{(t_s - t_0)^n - (t_s - t_1)^n}\right]^{\frac{1}{1-n}}$$

When $n = O$ this equation becomes indeterminate and the logarithmic form

$$\theta = \frac{t_1 - t_0}{\log_e \frac{t_s - t_0}{t_s - t_1}}$$

must be used.

When $n = 1$ the formula for θ is indeterminate since $U\theta = K$ for all values of S and the values of θ must be determined arithmetically.

The relations of the three coördinate values S, U and θ may best be shown by the four solids in Fig. 16. A is for the case where $n = 1$. In this case $U\theta$ is constant, the temperature rise is a straight line and U increases inversely as the temperature difference according to the hyperbolic law becoming infinity when the cooling water is heated to the steam temperature. B is the case where $n = O$. In this case U is constant, the curve of temperature rise follows the logarithmic law and $U\theta = N$ decreases for each added increment of surface. θ is the mean ordinate of the temperature rise curve. C is the case where $n = -1$. In this case both curves are asymptotic to the horizontal axis or axis of surface. D is the case where $n = \frac{1}{2}$ and best represents the experiments.

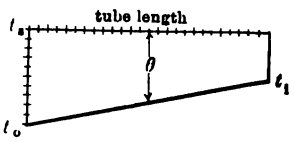
In all cases the volume of the solid represents the total heat trans $Q\ (t_1 - t_0)$ and the area at any section parallel to the plane of the U a is the heat transmitted at that portion of the surface.

For purposes of design, as U must be taken as the average of a throughout the condenser, the mean temperature difference is really perature difference at the location of the mean section $U\theta$.

DETERMINATION OF FORMULAE FOR VALUES OF U, S AND VARIOUS ASSUMED VALUES OF N

S = Cooling surface, sq. ft.
$N = U\theta$ = Total heat transfer per sq. ft. per hour, B.t.u.
U = Heat transfer per sq. ft. per hour per deg. m.t.d.
θ_m = m.t.d. = mean temperature difference
Q = Circulating water per
K = Constant determined t ment
t_s = Temperature of steam
t_0 = Temperature of circula at inlet
t_1 = Temperature of circula at outlet
t = Any temperature betw t_1

CASE 1: θ taken from curve. $\theta = t_s - \frac{t_1 + t_0}{2}$



Formula for S. Total amount of heat transmitted = the surface a transfer per sq. ft. per hour per deg. mean temperature di mean temperature difference.

$$S = \frac{Q\ (t_1 - t_0)}{U\theta}$$

In this case

$$U = \frac{K}{\theta}$$

$$S = \frac{Q}{K}\ (t_1 - t_0) = \frac{Q}{K}\ [(t_s - t_0) - (t_s + t_1)] = \frac{Q}{K}\ [(t_s - t_0) - (t_s$$

CASE 2: Assume that U is constant for all temperature differen

Then $\frac{dt}{ds}$ = rate of rise in temperature of water, also $\frac{U\ (t_s - t)}{Q}$ rise in temperature of water.

$$\frac{dt}{ds} = \frac{U(t_s - t)}{Q}, \quad ds = \frac{Q}{U}\int_t^{t_s} \frac{1}{(t_s - t)}\,dt, \quad s = -\frac{Q}{U}\log_e (t_s - t) + C, \quad U = K$$

When $s = 0$ $\quad t = t_0$

$$0 = -\frac{Q}{K}\log_e (t_s - t_0) + C \qquad s = -\frac{Q}{K}\log_e (t_s - t) + \frac{Q}{K}\log_e (t_s - t_0)$$

$$C = \frac{Q}{K}\log_e (t_s - t_0) \qquad s = \frac{Q}{K}\log_e \frac{t_s - t_0}{t_s - t}$$

When $s = S$ $\quad t = t_1$

$$S = \frac{Q}{K}\log_e \frac{t_s - t_0}{t_s - t_1}$$

$$\theta = \frac{Q(t_1 - t_0)}{SK} = \frac{Q(t_1 - t_0)}{K\left(\frac{Q}{K}\log_e \frac{t_s - t_0}{t_s - t_1}\right)} = \frac{t_1 - t_0}{\log_e \frac{t_s - t_0}{t_s - t_1}}$$

CASE 3: $\frac{dt}{ds}$ = rate of rise in temperature of water

$\frac{dt}{ds} = \frac{U\theta}{Q}$, $\frac{U\theta}{Q}$ = rate of rise in temperature of water, $dsU\theta = Qdt$.

Assume $U = \frac{K}{\theta^n}$

$$ds = \int \frac{Qdt}{\frac{K}{\theta^n}\theta} = \int \frac{Qdt}{K\theta^{1-n}}$$

$$\theta = t_s - t$$

$$ds = \int \frac{Qdt}{K(t_s - t)^{1-n}} = \frac{Q}{K}\int_{t = t_0}^{t = t_1} (t_s - t)^{n-1}\,dt$$

$$S = \frac{Q}{Kn}\left[(t_s - t_0)^n - (t_s - t_1)^n\right]$$

$$\theta = \frac{Q(t_1 - t_0)}{SU}$$

$$U = \frac{K}{\theta^n}$$

$$U = \frac{K}{\theta^n} = \frac{Q(t_1 - t_0)}{\frac{K}{\theta^n}\frac{Q}{Kn}\left[(t_s - t_0)^n - (t_s - t_1)^n\right]}$$

$$\theta = \frac{t_1 - t_0}{\theta^n n\left[(t_s - t_1)^n - (t_s - t_1)^n\right]}$$

$$\theta = \frac{\theta^n n\,(t_1 - t_0)}{[(t_s - t_0)^n - (t_s - t_1)^n]}$$

$$\frac{\theta}{\theta^n} = \frac{n\,(t_1 - t_0)}{[(t_s - t_0)^n - (t_s - t_1)^n]}$$

$$\theta^{1-n} = \frac{n(t_1 - t_0)}{[(t_s - t_0)^n - (t_s - t_1)^n]}$$

Taking $\frac{1}{1-n}$ root of each side

$$\theta^{\frac{1-n}{1-n}} = \theta = \left[\frac{n\,(t_1 - t_0)}{[(t_s - t_0)^n - (t_s - t_1)^n]}\right]^{\frac{1}{1-n}}$$

I wish to give credit to Charles A. Howard, Jun.Am.Soc.M.E., to H. R. Calloway, and particularly to P. E. Reynolds, now engineer of tests at the New York Edison Company, for their assistance in the preparation of this paper. Mr. Reynolds should also be credited with the working up of the three coördinate diagrams in the closure.

No. 1298

COMBUSTION AND BOILER EFFICIENCY

THE IMPORTANCE OF CARBON DIOXIDE AS AN INDEX TO COMBUSTION AND, IN CONNECTION WITH FLUE-GAS TEMPERATURE, TO BOILER EFFICIENCY

By Edw. A. Uehling, Passaic, N. J.

Member of the Society

It is now fully recognized by all progressive and observing engineers and managers of power houses that there is more room for economy in the boiler house than in any other part of the plant. It is therefore not due so much to lack of recognition of the fact that there is still from 5% to 25% of the available energy of the coal needlessly wasted that this waste continues to an appalling degree, as to the inherent difficulty in regulating combustion so that the loss may be reduced to a minimum.

2 A steam engine correctly designed, properly constructed, accurately adjusted and adapted to the work to be performed will give maximum economy. The attendant can do little or nothing either to increase or to decrease its efficiency. This is true also, and perhaps even to a greater degree, of the steam turbine and the dynamo. Certain definitely fixed and automatic adjustments having been found to give maximum economy, the efficiency will continue so long as these adjustments are maintained. An occasional economy test is all that is required to maintain maximum efficiency.

3 The efficiency of the steam generator depends on far more complex conditions, many of which are not only beyond control but are continually changing. Some of them are: First, *atmospheric conditions*, i.e., the barometric pressure, humidity of the atmosphere, direction and velocity of the wind, all of which affect combustion. Second, *the quality of the fuel*, which at best is never quite uniform, even when similar in kind, and often varies greatly in its con-

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tent of moisture, fixed carbon, volatile combustible matter, oxygen, ash, etc.; also its physical condition, unless specially prepared, may and often does vary from large lumps to fine powder. Third, *the condition of the boiler* as to setting, dirty heating surface, air infiltration, draft, etc. The grates become choked with slate and clinker, obstructing the air passage and causing irregular flow, resulting in a deficiency in one place and an excess in another. Every one of these variables affects the efficiency of the boiler furnace. Fourth, *the required output*, which varies in some plants between very wide limits, not infrequently from 50% overload to 50% below normal capacity in short intervals of time.

4 From the foregoing it becomes quite evident that steam-boiler economy is a complex problem, and no matter how well a boiler may be designed and how perfectly constructed, it cannot be permanently adjusted to operate with maximum efficiency under the varying conditions which obtain, even under the most favorable circumstances. Permanent adjustments of a steam boiler cannot be made, as in a steam engine, to obtain maximum efficiency.

5 The heat energy carried off by the flue gas in general boiler-room practice is rarely as low as 15% and not infrequently reaches 40% of the calorific value of the fuel burned under the boiler.

6 This loss is made up of two distinct factors, the sensible heat of the flue gas and the potential heat of the combustible constitutents it contains. The former varies directly as the stack temperature and inversely as the percentage of CO_2. The latter is independent of the stack temperature, but for any given percentage of combustible constitutents in the flue gas the loss also varies inversely as the percentage of CO_2. The only heat loss that is independent of the percentage of CO_2 in the flue gas is that due to the moisture contained in the fuel, but it is dependent on the stack temperature. The percentage of CO_2 and the stack temperature are, therefore, the two controlling factors.

7 For any given boiler and setting driven at a given rate the temperature of the flue gas depends on the condition of the heating surface and on the amount of air infiltration. When the heating surface becomes dirty, either inside or outside, or both, the stack temperature will be correspondingly higher, other conditions being the same. Air infiltration lowers the stack temperature in proportion to its ratio to the actual products of combustion. We have, therefore, two conflicting conditions that influence the stack temperature. Because of dirty heating surface, it should be above normal, but air

nfiltration may actually bring it below normal, so that the stack temperature alone cannot be depended upon as an index either to economical or wasteful operation, especially since it gives no clue to the efficiency of the furnace.

8 When excessive air infiltration takes place, it becomes manifest at once by an abnormally low percentage of CO_2, so that a knowledge of the latter is necessary to understand the true significance of the former. Hence, it is evident that to produce maximum economy, or even good average results, some means should be provided to indicate to the attendant continuously what his fires are doing.

9 Provided the boiler is properly designed and set and is otherwise in proper condition, i.e., clean inside and out, its economy depends entirely on the regulation of the furnace. This again depends upon the regularity of fuel and air supply in the correct proportion and through the proper channels. Since the composition of the products of combustion gives immediate evidence of the furnace operation, it follows that in the analysis of the flue gases lies the key to the attainment of maximum efficiency, and the most progressive engineers and managers of power plants have employed gas analysis in a more or less thorough manner as a means for obtaining increased boiler house economy.

10 Since the excess of oxygen is necessary for complete combustion, it is held by some combustion experts that O is a better index to the efficiency of combustion and boiler economy than CO_2.

11 A study of the diagrams (Figs. 1 to 4) and the analyses from which they are plotted, may lead to the conclusion that the percentage of O might answer as well as the percentage of CO_2, but hardly better. When we consider that CO_2 is very much more readily determined than O, and that there are a number of practicable instruments on the market that will autographically record the percentage of CO_2 in the flue gas at short intervals, one of which will make a continuous record and at the same time indicate the percentage of CO_2 at the boiler front, there can be little room for doubt as to which of the constituents is the better adapted to serve as the index of economical combustion.

12 It may be questioned whether a knowledge of the percentage of CO_2 is sufficient for economical firing. Is it not necessary to know the percentage of oxygen (O), carbon monoxid (CO), hydrogen (H) and hydrocarbons (C_xH_y) as well?

13 For scientific tests and investigations, complete anal
the products of combustion should always be made, and if in a
a heat balance is to be made, it is necessary to determine the
of the coal, the volume or weight of the water, the quality of th
as to entrained moisture and superheat, and the weight of
the unconsumed carbon it contains. It is evident that su
can be carried on only by an expert with the necessary a
apparatus and the help of competent assistants. They are
fore, not available for every-day practice. Occasional t
undoubtedly of great value, especially for the purpose of dete
the most economical percentage of CO_2 for the kind of fuel u
the conditions prevailing, but what is needed is a continuous
able index. For such index the choice can lie only betw
and O and, for reasons already given, CO_2 is much to be p

14 Figs. 1 to 4 and the analyses which they represe
conclusively that under normal conditions of combustion th
very definite relation between the percentage of CO_2 and O c
in the flue gas. The percentage of O falls almost exactly in t
ratio as CO_2 goes up and vice versa. The analyses also sh
clusively that there is no relation between either O or CO_2
High O and low CO_2 is no guarantee that CO may not be
nor does it follow that high CO_2 and low O means incompl
bustion. All that we can discern with certainty is that th
tendency toward higher CO as the percentage of CO_2 goes u
tendency increases very moderately at the lower range of
more and more rapidly as the maximum percentage of CO_2 is
Since the ratio of carbon burned to CO to that burned to CO
$\frac{P_c}{P + P_c}$ (see Par. 44), it follows that the loss (L_c) due to
monoxid for the same percentage of CO varies inversely as
centage of CO_2, e.g., 1% of CO in flue gas containing 5% of CO
as great a loss as 3% of CO associated with 15% of CO_2. T
holds true of the loss due to all the combustion products
exception of the moisture contained in the fuel. The gene
clusion that the chimney heat loss varies inversely as the pe
of the CO_2, in flue gas seems therefore warranted. M
influences are considered in Pars. 20 to 22.

15 The sum of the percentages of CO_2, O and CO con
flue gas varies with the excess of air, the degree of comple
combustion, the composition of the fuel and the temper
which the gas is analyzed. When combustion is complete

fuel consists of carbon only, the sum of CO_2 and O cannot exceed the percentage of oxygen in the air, viz: 21% (see Par. 38). It will always be less than this, because the gas is presumably saturated with moisture, at the temperature at which analysis is made, amounting to 1.16 and 5.55% respectively at 62 and 92 deg., so that the sample contains 4.4 less dry gas in the latter than in the former case, causing corresponding difference in sum of the oxygen constituents.

16 *Effect of Incomplete Combustion.* Since every molecule of O forms two molecules of CO, the gas from pure carbon can contain

$$\frac{42 \times 100}{42 + 79} = 34.7\% \text{ of CO}$$

hence the presence of CO increases the sum of the oxygen constituents by $\frac{34.7 - 21}{21} = 0.65$ of its volume. This effect, however, will be more than neutralized in normal flue gas by the presence of water vapor and hydrocarbons, so that analyses showing over 21% must be looked on with suspicion.

17 In burning fuel containing any considerable quantity of hydrogen, the sum of CO_2+O_2+CO will always be proportionately less than 21% in normal flue gas, because all the oxygen which combines with the hydrogen forms water vapor, which is condensed to the point of saturation, while the nitrogen remains as a diluent. Carbon and hydrogen require respectively 152 and 457 cu. ft. of pure air (at 62 deg.) for complete combustion per lb. (see Par. 38 and 48). The carbon produces 31.92 cu. ft. of CO_2, 120.08% of nitrogen, whereas the hydrogen combustion product consists of 351 cu. ft. of nitrogen only in measurable gas. Thus when burning a pure fuel in which for example, the hydrogen ratio $\frac{H_2}{C} = 0.06$, assuming complete combustion with the theoretically required volume of pure air, we get $\frac{152 \times 21}{152 + (361 \times 0.06)} = 18.4\%$ of CO_2 against $\frac{152 \times 21}{152} = 21\%$ of CO_2 from pure carbon, a difference of 2.6%. If the above fuels are burned with 50% excess of air, we get $\frac{152 \times 21}{228 + (590 \times 0.06)}$ $= 12.12\%$ CO_2 and $\frac{152 \times 21}{228} = 14\%$ CO_2 respectively. This CO_2 would be accompanied by $\frac{(75 + 13.7) \times 21}{228 + 35.4} = 7.15\%$ of O in the former

and $\frac{76 \times 21}{228} = 7\%$ of O in the latter case, making the sum of the oxygen components respectively 19.27% and 21%, a difference of 1.73%. There are many modifying conditions which affect the sum of the oxygen components of which the temperature at which the gas is analyzed is one. Supposing the gas from the hydrocarbon fuel to be analyzed saturated at 92 deg., and that from the carbon fuel saturated at 62 deg., we would get $19.27 - (19.27 \times 0.044) = 18.32\%$ and $21 - (21 \times 0.0116) = 20.76\%$, making the difference 2.44% instead of 1.73% as found for the dry pure gas.

18 This is an extreme case, but it shows that large variations may legitimately occur in the sum of the oxygen components contained in combustion products. It also shows that the temperature at which gas analyses are made should be taken into consideration. It brings out the further fact that the maximum percentage of CO_2 that may be contained in flue gas decreases as the ratio of carbon to hydrogen in the coal increases, from which it becomes evident that the most economical percentage of CO_2 must vary with the kind of fuel. It will be several per cent higher with anthracite than with bituminous coal, and varies in the latter with the ratio of carbon to available hydrogen.

19 The highest practicable furnace efficiency obtains when the greatest possible part of the potential energy contained in the coal is converted into sensible heat by combustion. The highest boiler efficiency results when a minimum of this heat is carried off by the flue gas. The former is realized when combustion is complete, the latter when the weight and temperature of the flue gas are a minimum. Since the weight of flue gas decreases as the percentage of CO_2 increases, high boiler efficiency requires high CO_2.

20 On the other hand, when the furnace is run so as to produce a maximum percentage of CO_2 there is danger of reducing its efficiency because of incomplete combustion due to a minimum of free oxygen. It would seem, therefore, that the highest combined efficiency of boiler and furnace would be obtained when the gain due to reduced weight of flue gas, i.e., due to an increased percentage of CO_2, is balanced by the loss due to incomplete combustion.

21 The most economical percentage of CO_2 varies theoretically with the ratio of available hydrogen to carbon $\left(\frac{H_a}{C}\right)$, but in practice it is influenced by many modifying conditions. In every case, however, there is a percentage of CO_2 which gives best results. Its value

as an index, therefore, is not dependent on the kind of fuel used or the local conditions existing.

22 Next to careless or unskilful firing, air infiltration causes the greatest loss in the flue gas. Unless especially provided against, it is rarely less than 15 to 20% of the volume of the flue gas and not infrequently reaches 50% and over when cracks in the settings are allowed to exist and warped and badly fitting cleaning doors are tolerated. Professor Breckenridge, in his discussion of the boiler tests carried on by the Government at St. Louis under his direction, estimates the air infiltration at from 25 to 30%, and it would be presumptuous to assume that the boilers used for these tests were not in at least as good condition as those in the average power plant.

23 We have shown in Par. 17 that when burning coal in which $\frac{H_a}{C} = 0.06$ with 50% excess of air the flue gas should contain 12.12% CO_2 and 7.15% O. It would, therefore, seem reasonable to conclude that when burning coal in which the ratio $\frac{H_a}{C}$ does not exceed 0.05, if the CO exceeds 0.2% or at most 0.3% in flue gas containing 12% to 14% of CO_2 and 7% to 5% of O there is something wrong with the method of firing, the furnace, the construction, the setting or all of them.

24 In Pars. 15 to 18 an attempt is made to show why the sum of the oxygen components contained in flue gas does vary and to what extent it may vary legitimately. It was shown that a considerable variation may be due to a variation in the temperature at which the gas is analyzed, that the presence of CO augments the sum of the oxygen components by 0.65 of its value, and that the presence of H_2 in the fuel reduces this sum very materially. It follows, then, that for similar fuel the higher percentage of CO should coincide with the higher sum of the oxygen components.

DIAGRAMMATIC REPRESENTATION OF ANALYSES

25 The diagrams, Figs. 1 to 4, were plotted from the averages of over 1000 separate analyses. These analyses were classified, first, according to their source, and secondly, according to the sum of their oxygen components. Tables were arranged, first, with reference to the per cent of CO_2 and, secondly, with reference to the per cent of O contained in the gas. Space does not permit includ-

ing these tables: it must therefore suffice to say that the di
were plotted from the averages of each group varying 0.1%
and O respectively. The straight lines represent the the
amounts of CO_2 and O which the combustion products would
if pure carbon were burned with pure air. The analyses were
with regard to the percentage of CO_2 and O respectively
CO_2 was placed in its proper position on the theoretical CO_2
the percentages of CO_2 and then the accompanying percenta
and CO were plotted on the same ordinate in the position ca
by their value. In the same manner the O was placed on the
ical oxygen line and the CO_2 and CO were plotted according
values on the same ordinate. To show the values of CO more
they are multiplied by five.

26 Fig. 1 shows that the percentage of O diminishes as
increases, and vice versa, the percentage of CO_2 increases
O becomes less. It will be noted that both the O and C
converge toward the theoretical line as the CO_2 diminishes,
as it should be if the analyses are correct, because when th
zero, the percent of O must be that of the air, viz., 21%. The
of divergence from the theoretical line towards zero O
on the value of $\frac{H_2}{C}$ in the fuel.

27 Considering the great variety of fuels represented by t
ernment analyses, it is remarkable with what uniformity the
O vary in accordance with what should be expected from th
considerations. The extension of the diagram is plott
analysis of flue gas obtained from a government locomotive bo
From this we may be justified in concluding that the rel
CO_2 to O shown in Fig. 1 holds true for all ordinary condition
ple combustion. It therefore follows that if we know the pe
of CO_2 contained in the products of combustion we may in
it with a practical degree of approximation the accompany
centage of O, and vice versa.

28 That no such reliable relation exists between the
either of the former has already been stated. That this s
so becomes quite evident when we consider that the relation
CO_2 and O depends on a natural law, whereas the percenta
in a large degree depends on caprice.

29 The CO line in Fig. 1 illustrates the irregularity of t
ponent. It was stated at the outset that the tendency
higher percentage of CO in flue gas becomes increasingly g

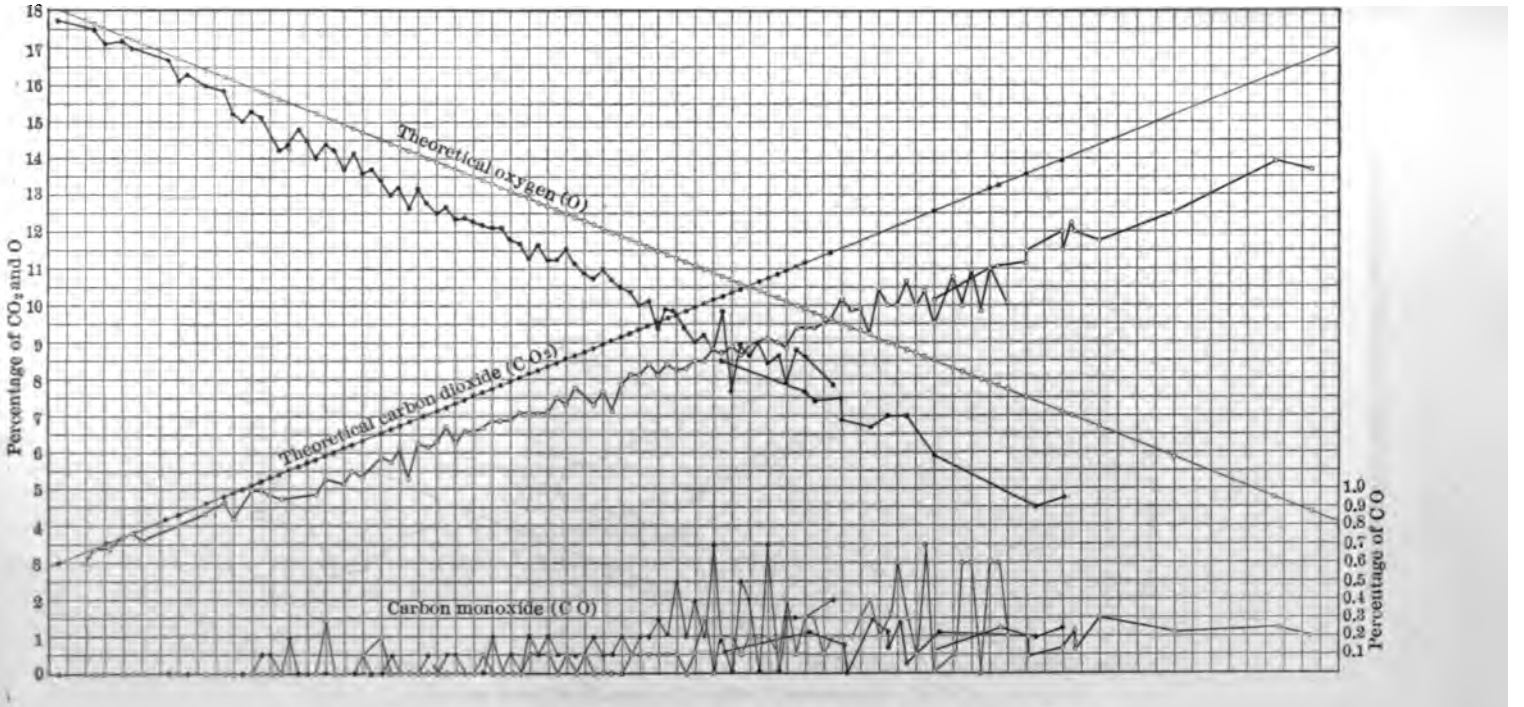


FIG. 1 DIAGRAMMATIC REPRESENTATION OF ANALYSES, GOVERNMENT TESTS

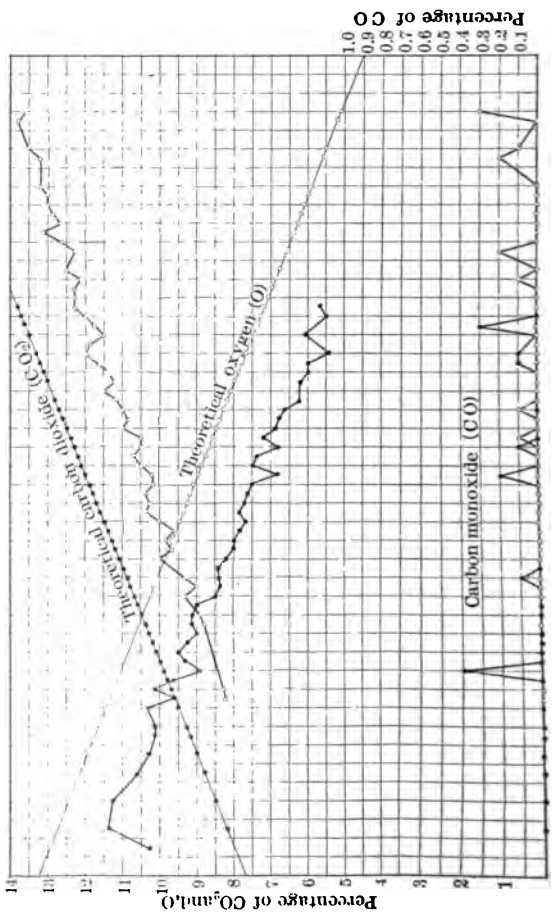
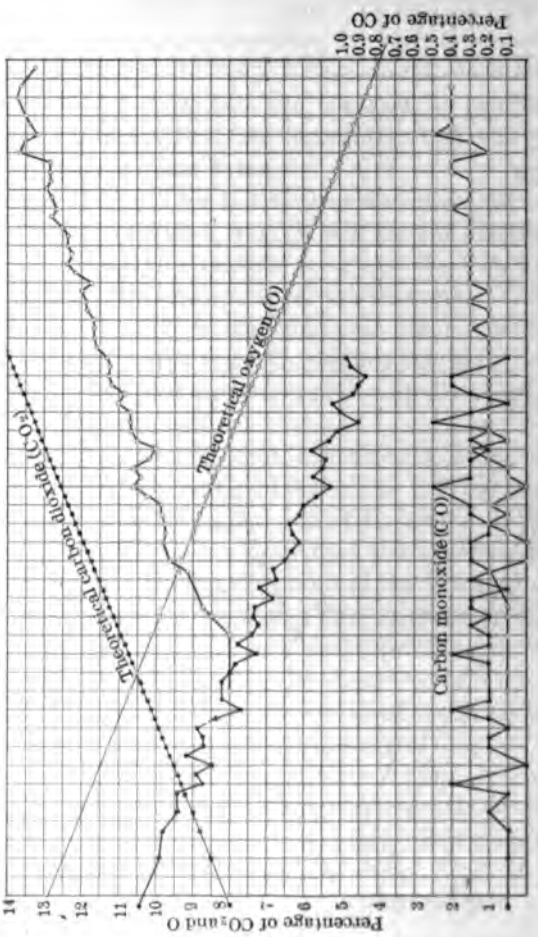


FIG. 2 DIAGRAMMATIC REPRESENTATION OF ANALYSES FROM A LARGE POWER PLANT
SUM OF OXYGEN COMPONENTS 19% AND ABOVE



[FIG. 3 DIAGRAMMATIC REPRESENTATION OF ANALYSES, SIX-HOUR SAMPLES FROM LARGE POWER PLANT. OXYGEN COMPONENTS 18–19%

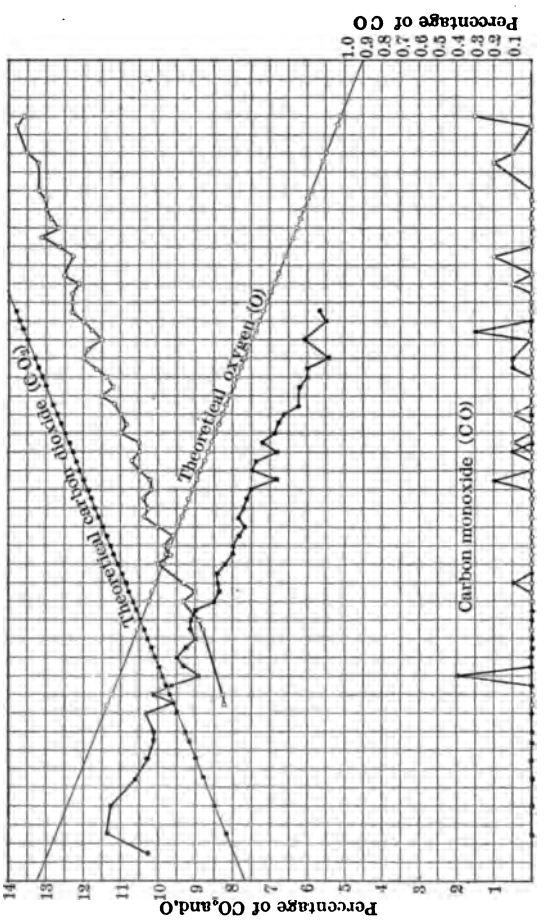


FIG. 2 DIAGRAMMATIC REPRESENTATION OF ANALYSES FROM A LARGE POWER PLANT
SUM OF OXYGEN COMPONENTS 19% AND ABOVE

the percentage of CO_2 goes up; but the diagram shows a maximum of over 0.4% of CO with CO_2 between 10% and 11%, whereas with CO_2 between 11% and 14% the CO does not average above 0.2%. This apparent anomaly is explained by the fact that Government analyses include from 20 to 30% of infiltrated air and that the real combustion products contained about 25% more CO_2 and 25% less O than the analyses show. In reality, therefore, the high CO readings occurred with CO_2 from 12.5 to 13.75%. This would place the high CO in its proper relation to CO_2, but the contrast as compared with the CO found in the flue gas of the locomotive test still remains and is evidence of uneconomical firing.

30 Passing to Fig. 2 we notice the same characteristics as in Fig. 1, viz., the O line follows a trend which should meet the theoretical O line at 21% when CO_2 reaches zero, and the CO_2 follows a trend which would meet the zero point of the theoretical CO_2 line when O reaches 21%. The CO is irregular and has a moderate tendency towards higher values as the CO_2 reaches the higher values. With the exception of the few analyses previously discussed, this diagram shows very good combustion.

31 Fig. 3 corroborates what has already been said about the analyses from which it was plotted. The CO line is irregular and high, and only slightly higher with CO_2 above 11% than below. Both the CO_2 and the O line show that the analyses are deficient in the O components, nor does the trend of the O line converge toward the theoretical line as it should. The correctness of the analyses must, therefore, stand questioned, and other than showing this fact, little value can be attached to the diagrams in Fig. 3.

32 The suspicion as to the correctness of the analyses is strengthened to an even greater extent by a study of Fig. 4. The analyses appear to be particularly faulty with the higher CO_2 and the correspondingly lower O content. The high and erratic CO line shows that the firing must have been irregular and bad. But reliable conclusions cannot be drawn from this diagram except that at least a large number of the analyses cannot be considered reliable.

CALCULATION OF HEAT CARRIED OFF BY THE FLUE GAS

33 In Appendix No. 1 an attempt has been made to formulate simple equations by which the heat and heat energy carried off by the flue gas can readily be calculated for all kinds of fuel, provided we have a correct analysis of the fuel burned and the flue gas produced.

CONCLUSIONS

34 We must conclude from these calculations that the perc of CO_2 and the stack temperature are the two controlling fac the production of furnace and boiler efficiency. In view of tl that both of these components are so easily determined an apparatus is in existence which will continuously indicate and them, it is lamentable that more general use is not made o indexes.

35 There is today no valid reason why scientific methods not prevail in securing fuel, as well as in consuming it, esp for power purposes, nor is there any reason why consumers quantities of coal should be ignorant of its ultimate, as wel proximate composition.

36 It is not generally feasible, nor is it at all necessary, in obtain the most economical results, that calculations be based ultimate analysis of the coal, but a full analysis of the flue gas form part of the daily routine. Inasmuch, however, as th economical percentage of CO_2 varies considerably with the fuel used, and also to some extent with the method of firing, mechanical, the kind of stoker and rate of driving, it becom desirable, if not absolutely necessary, to make a series of which all the essential elements are determined.

37 Having established the most economical value of C component of the flue gas will serve as a correct guide to the An automatic record, preferably a continuous one, for the en of the greatest value. If, in addition, the stack temper indicated for the fireman and recorded for the engineer in there should be little difficulty in getting maximum efficienc

APPENDIX No. 1

CALCULATION OF HEAT CARRIED OFF BY THE FLUE GAS

NOTATION

A = weight of air consumed in burning a weight of fuel containing 1 lb. of carbon

A_c = theoretical weight of air required to burn 1 lb. of carbon

A_h = theoretical weight of air required to burn 1 lb. of hydrogen

A_e = weight of air in excess of that theoretically required to burn a weight of fuel containing 1 lb. of carbon

F_c = weight of fixed carbon per lb. of fuel

V_c = weight of volatile combustible per lb. of fuel

$R = \frac{V_c}{F_c}$ = ratio of volatile combustible to fixed carbon in fuel

$R' = \frac{H + C_xH_y}{C}$ = ratio of the volatile combustible to the total carbon in liquid or gaseous fuel

$H_a = H - \frac{O}{8}$ = weight of available hydrogen in fuel per lb. of carbon

O = weight of oxygen in fuel per lb. of carbon

$W_h = O + \frac{O}{8}$ = weight of water of hydration in fuel per lb. of carbon

W_m = weight of water (moisture) in fuel per lb. of carbon

P_a = percentage of moisture contained in air

P = percentage of CO_2 contained in flue gas

P_c = percentage of CO contained in flue gas

P_{vc} = percentage of volatile combustible contained in flue gas, i.e., H and C_xH_y

P_e = percentage of excess of air

L = B.t.u. loss due to sensible heat in flue gas per lb. of carbon in fuel when burned with dry air

L_c = B.t.u. loss due to fuel value of CO in flue gas per lb. of carbon in fuel when burned with dry air

L_{vc} = B.t.u. loss due to fuel value of $(H + C_xH_y)$ in flue gas per lb. of carbon in fuel when burned with dry air

L_v = B.t.u. loss due to moisture in air per lb. of carbon

L_m = B.t.u. loss due to moisture in fuel per lb. of carbon

L_h = B.t.u. loss due to hydrated moisture in fuel

L_t = B.t.u. loss due to all of the above losses per lb. of carbon in fuel burned

T = temperature of flue gas on leaving boiler
t = temperature of air in boiler house
S = specific heat of dry flue gas
S_w = specific heat of water vapor

Pure air contains	by weight	by volume
Oxygen (O_2)	23 %	21 %
Nitrogen (N_2)	77 %	79 %

Weights (lb.) per cu. ft. at 62 deg.fahr.		Specific Heats (S)	
Dry air	0.0761	Air	0.237
N_2	0.0738	N_2	0.244
CO	0.0735	O_2	0.217
CO_2	0.1159	CO_2	0.217
H_2O	0.0472	CO	0.247
		Average	0.23

Specific heat (S_w) of H_2O = 0.48
Atomic weight of H = 1
Atomic weight of C = 12
Atomic weight of O = 16

COMPLETE COMBUSTION WITH THEORETICAL AMOUNT OF AIR

38 One pound of carbon theoretically requires 11.6 lb. or 152 cu. ft. of air for complete combustion, forming 12.6 lb. of combustion product. According to Avogadro's law a molecule of CO_2 occupies the same space as a molecule of O_2, hence the combustion product consists of 21% CO_2 and 79% N_2 by volume. Thus, when burning carbon with its theoretically required volume of air $P = 21\%$, which is the maximum amount obtainable, and the heat carried off by the combustion products will be the minimum, viz: $(A_c + 1) \times (T - t)\, S$. Since $A_c = 11.6$ per lb. of carbon we have

$$L = 12.6\ (T - t)\ S \qquad [1a]$$

Substituting the value of S and reducing, we have

$$L = 2.9\ (T - t) \qquad [1]$$

COMPLETE COMBUSTION OF CARBON WITH AN EXCESS OF AIR

39 When carbon is burned with an excess of air (A_e), which by volume equals $\frac{A_e}{0.0761}$ cu. ft., then

$$P = \frac{21 \times 152}{152 + \frac{A_e}{0.0761}}$$

from which we get $A_e = \frac{21 \times 11.6}{P} - 11.6$. The total weight of air, $A = A_c + A_e$.

40 Substituting the values of A_c and A_o, we have

$$A = \frac{21 \times 11.6}{P}$$

$$L' = (1 + A) \times (T - t)\, S \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [2a]$$

Substituting the values for A and S and reducing to the lowest terms we have

$$L' = \left(0.23 + \frac{56}{P}\right) \times (T - t) \ldots\ldots\ldots\ldots\ldots\ldots [2]$$

41 The percentage of excess of air for carbon will be

$$P_c = \frac{A_o \times 100}{A_c}$$

Substituting the values of A and A_o and reducing, we have

$$P_c = \frac{2100}{P} - 100$$

INCOMPLETE COMBUSTION OF CARBON

42 If combustion is incomplete, i.e. if some of the carbon passes off with the combustion product as CO, a loss of potential heat energy takes place. Since a pound of carbon burned to CO develops only 4350 B.t.u. instead of 14,500 when burned to CO_2, we have a loss of 14,500 − 4350 = 10,150 B.t.u. for every pound of carbon which passes off as CO.

43 The burning of carbon to CO requires only one-half the weight of air required for CO_2; the presence of CO in the flue gas must, therefore, tend to make the value of A_c too great; but since P_c is always relatively very small, the presence of CO will not appreciably affect the value of L.

LOSS DUE TO CO IN FLUE GAS

44 When the percentage of CO (P_c) is known, the heat loss due to its presence (L_c) is easily determined. The weight of carbon in a molecule of CO is the same as in a molecule of CO_2 and it follows from Avogadro's law that the weight of carbon burned to CO is to that burned to CO_2 as the per cent of CO is to the per cent of CO_2 contained in the combustion product. Thus, letting X = the weight of carbon burned to CO, we have $\frac{X}{1 - X} = \frac{P_c}{P}$ from which we get $X = \frac{P_c}{P + P_c}$ = carbon burned to CO per unit of carbon contained in the fuel. Since CO burned to CO_2 per unit of carbon develops 10,150 B.t.u., we have $L_c = 10{,}150 \frac{P_c}{P + P_c}$. For the total loss when dry carbon is burned with dry air, we have

$$L_t = L' + L_c \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [3a]$$

Substituting the values of L' and L_c, we have

$$L_t = \left(0.23 + \frac{56}{P}\right) \times (T - t) + 10{,}150 \frac{P_c}{P + P_c} \quad \ldots\ldots\ldots\ldots [3]$$

EFFECT OF MOISTURE IN FUEL AND AIR

45 Thus far we have considered both fuel and air to be dry, a condition which never exists in practice. The humidity in the air may vary from a fraction of one per cent to several per cent and commercial fuel is never dry. Coke or charcoal, as well as mineral coal, may contain 10% or more of moisture.

46 Atmospheric moisture exerts a chilling effect on the fire because of its high specific heat and because at least part of it will be decomposed. But since under normal conditions the hydrogen which was set free by decomposition will reunite with the oxygen from the air in the combustion chamber and will evolve as much heat there as was absorbed in the fuel bed in setting it free, there results no heat loss due to this double reaction. It will be necessary, therefore, to consider only the sensible heat carried off by moisture contained in the air, hence

$$L_v = \left(A \frac{P_a}{100}\right) \times (T - t)\, S_w$$

Substituting the values of A and S_w and reducing to lowest terms, we have

$$L_v = \frac{1.17\, P_a}{P} \times (T - t)$$

47 Moisture in fuel (W_m) exists in the form of water, which must first be heated to 212 deg. and then evaporated, the vapor passing off at the temperature of the flue gas. Since the latent heat of evaporation is 966 B.t.u. and the specific heat of water vapor is 0.48, we have

$L_m = (212 - t + 966)\, W_m + (T - 212)\, 0.48\, W_m = (1076 - t + 0.48\, T)\, W_m$

Hence, when burning wet fuel with natural air, we get for the total loss

$$L_t = L' + L_c + L_v + L_m \quad \ldots\ldots\ldots\ldots\ldots\ldots [4a]$$

Substituting values and reducing to lowest terms, we get

$$L_t = \frac{(56 + 1.17\, P_a) \times (T - t)}{P} + \frac{10{,}150\, P_c}{P + P_c}$$
$$+ 0.23 \times (T - t) + 1076 - t + (0.48\, T)\, M \quad \ldots\ldots\ldots\ldots [4]$$

CALCULATION OF HEAT LOST IN THE FLUE GAS WHEN HYDROGEN FORMS AN APPRECIABLE PART OF THE FUEL

48 In the chemical reaction which constitutes the combustion of hydrogen, 8 lb. of oxygen and 1 lb. of hydrogen unite to form 9 lb. of water vapor.

This requires 34.8 lb. or 457 cu. ft. of air and results in 35.78 lb. of combustion product. In commercial flue-gas analysis no account is taken of the moisture, hence nitrogen only is determined in the combustion product from hydrogen. The burning of 1 lb. of hydrogen with the theoretically required volume of air therefore results in 361 cu. ft. of nitrogen.

49 If the fuel consists of carbon and hydrogen and is burned with the theoretically required air, we have $P = \frac{152\ C \times 21}{152\ C + 361\ H_a}$. Placing $C = 1$ and reducing volume to weight, $P = \frac{11.6 \times 21}{11.6 + 26.7\ H_a}$. If there is excess air, we have

$$P = \frac{11.6 \times 21}{11.6 + 26.7\ H_a + A_e},$$ from which we get

$$A_e = \frac{11.6 \times 21}{P} - 11.6 - 26.7\ H_a$$

and

$$A = A_c + A_h + A_e = \frac{11.6 \times 21}{P} + 8.1\ H_a$$

$$L'' = (A + 1) \times (T - t)\ S + 9\ H_a\ (T - t)\ S_w$$

Substituting for A, A_e, S and S_w their values and reducing to lowest terms we have

$$L'' = (0.23 + \frac{56}{P} + 6.2\ H_a) \times (T - t)$$

50 This formula will give correct results for anhydrous fuel containing hydrogen when burned with dry air, assuming complete combustion. When burning pure carbon fuel (coke or charcoal), CO is the only fuel constituent contained in the combustion product, but as soon as the fuel contains an appreciable amount of volatile combustible, both hydrogen and hydrocarbons may appear in the fuel gas. The loss equation when burning dry hydrocarbon fuel with natural air becomes

$$L_t = L'' + L_v + L_c + L_{vc} \quad [5a]$$

The last term of this equation will increase in importance with the volatile combustible (V_c) in the fuel. It will be zero with coke and charcoal, insignificant with anthracite, it may approach the value of L_c in bituminous, and will probably equal or even surpass it in liquid and gaseous hydrocarbon fuels.

51 Because of the difficulty encountered in determining the percentage of H and C_xH_y in flue gas, little or nothing is known as to their quantitive relation to CO_2 and CO. It may be assumed, however, with a considerable degree of certainty that if a fuel is burned to such a degree of completeness that no measurable amount of CO is found in the flue gas, H and C_xH_y will also be absent. It would even seem probable, and therefore reasonable to assume, at least until the contrary has been demonstrated, that in the combustion of any hydrocarbon fuel the absence of CO may be considered as evidence of complete combustion. But when CO is present in the flue gas from hydrocarbon fuel, H and C_xH_y constitutents must also be suspected and should be included

in any formula which pretends to express the total loss of heat and h through the chimney, even though it is not practicable to determine th constituents in the daily flue-gas analyses.

52 It is reasonable to suppose that the tendency for H and C_xH_y to associated with CO when combustion is incomplete will increase with the v tile combustible (V_c) contained in the fuel. We may, therefore, assume t the percentage of H and C_xH_y in the flue gas is to the CO as the percent of volatile combustible in the coal is to the fixed carbon. Representing latter ratio by R, we have $R = \frac{P_{vc}}{P_c}$, from which we get $P_{vc} = P_c R$.

53 For liquid and gaseous fuels containing little or no fixed carbon we probably not be far wrong if we assume this ratio to be equal to the rati the hydrogen and hydrocarbon combustibles to the total carbon conten the fuel, i.e.,

$$R' = \frac{H + C_xH_y}{C} = \frac{P_{vc}}{P_c}$$

Hence

$$P_{vc} = P_c R'$$

54 Then if we let the heat value of the hydrogen and hydrocarbon com tibles in the flue gas equal that of CO, volume for volume, we have

$$L_{vc} = 10{,}150\, P_c R$$

$$L_t = L'' + L_v + L_c + L_{vc} \ldots\ldots\ldots\ldots$$

Substituting the values previously determined and reducing to lo terms, we have

$$L_t = \frac{(56 + 1.17\, P_a) \times (T - t)}{P} + \frac{10{,}150\ (P_c + P_c R')}{P + P_c}$$

$$+ (0.23 + 6\, H_a) \times (T - t) \ldots\ldots\ldots\ldots$$

55 There are no experimental data at hand to prove or disprove the sub tial correctness of the above relation. All that can be said in its favor is it would appear reasonable that such a relation exists between the CO a other combustible constituents contained in flue gas. Equation [5] r sents the total heat loss up the stack when burning liquid or gaseous fu from moisture.

WATER OF HYDRATION

56 All mineral coals contain water in two forms: moisture (W_m), water which can be driven off by drying at about 212 deg.; and water of h tion (W_h), which passes off at much higher temperatures with the v combustible matter, the estimation of which is ordinarily but wrongly in in the latter. True moisture (W_m) has already been considered.

57 If we know the weight of oxygen contained in the coal, the w hydration is determined by the equation $W_h = O + \frac{O}{8}$, i.e., 1 lb. of oxyge

ıes with $\frac{1}{8}$ lb. of hydrogen and forms $\frac{9}{8}$ lb. of water. We therefore have

$$L_h = 1.125 \times O \times (T - t)\, S_w = 0.54 \times O \times (T - t)$$

ıe total sensible and potential heat carried off by the flue gas from bituminous al therefore becomes

$$L_t = L'' + L_v + L_c + L_{vc} + L_m + L_h \quad \ldots\ldots\ldots\ldots [6a]$$

bstituting and arranging terms, we have

$$= \frac{(56 + 1.17\, P_a) \times (T - t)}{P} + \frac{10{,}150\ (P_c + P_c R)}{P + P_c} + (0.23 + 0.54 \times O)$$

$$\times (T - t) + (1076 - t) + 0.48T + W_m + 0.23 \quad \ldots\ldots\ldots\ldots [6]$$

om these heat loss equations we see that the loss of heat by way of the chimy is the sum of a number of distinct components; and that the loss occurs in o ways, (*a*) sensible heat and (*b*) unconsumed combustible.

38 When burning carbon fuel the loss components are

$$L_t = L + L_c + L_v + L_m \quad \ldots\ldots\ldots\ldots [4a]$$

ıe values of these components are

$$L' = (0.23 + \frac{56}{P}) \times (T - t)$$

$$L_v = \frac{1.17\, P_a}{P} \times (T - t)$$

$$L_c = \frac{10{,}150\, P_c}{P + P_c}$$

$$L_m = (1076 - t + 0.48\, T)\, W_m$$

ıen burning mineral coal the loss components are

$$L_t = L' + L_v + L_c + L_{vc} + L_m + L_h \quad \ldots\ldots\ldots\ldots [6a]$$

e values of these components are

$$L'' = (0.23 + \frac{56}{P} + 6.2\, H_a) \times (T - t)$$

$$L_v = \frac{1.17\, P_a}{P} \times (T - t)$$

$$L_c = 10{,}150 - \frac{P_c}{P + P_c}$$

$$L_{vc} = 10{,}150\, \frac{P_c R}{P + P_c}$$

$$L_m = (1076 - t + 0.48\, T)\, W_m$$

$$L_h = 0.54 \times O \times (T - t)$$

39 From the values of the components of equation [4*a*] we see that the loss e to the first three decreases directly as the CO_2 increases and the loss due the first, second and fourth increases directly with the temperature of the aping flue gases. Similarly, we see from the values of the components of ıation [6*a*] that the loss decreases as the CO_2 increases in the first four comıents, and increases with the flue-gas temperature in the first, second, fifth d sixth.

DISCUSSION

O. H. BATHGATE[1]. The paper attacks a broad and important subject and is one that deserves careful consideration. Little exception can be taken to any of the author's statements, though I find that several very important factors necessary for conclusions have been either omitted or not given their proper value. Referring to Par. 3, second condition, a proximate analysis of coal is insufficient for the purpose intended. A separate determination of sulphur is necessary to associate the quality of coal with efficient steam generation.

Referring to Par. 12, I agree with the author that for daily boiler-room practice when the maximum CO_2 is likely to be below 12 or 13%, the omission of the remaining gas constituents is not serious and for the average fireman the simplifying of such matters tends to greater efficiency.

I take exception to the last clause of the second sentence in Par. 13, for I believe that a plant where the CO_2 is determined either manually or automatically, should also provide a means for determining the carbon in the ash. Gas and ash analyses are equally essential to a complete knowledge of combustion, for in actual experience I have found firemen sacrificing coal to the advantage of a high CO_2 record. This indicates that gas analysis in itself is not necessarily a true index of boiler efficiency.

The last sentence of Par. 22 gives a method which may be followed to advantage in checking over large numbers of analyses made under approximately similar conditions.

Referring to Mr. Uehling's conclusions that CO_2 and stack temperature are controlling factors in the production of furnace and boiler efficiency, I would suggest that a determination of carbon in the ash is also an essential factor.

[1] Foreman's Assistant, Penna. Tunnel and Terminal R. R. Co., Long Island City, N. Y.

Boiler-room efficiency can be increased by using a reliable CO_2 recording apparatus, but my experience with three different types and investigations of as many more has led me to the conclusion that there is at present no practical automatic CO_2 apparatus available for continuous boiler-room operation.

To develop the highest efficiency, I would recommend running a single boiler on a continuous test under strictly operating conditions, noting quantities of steam generated and coal consumed and recording all conditions entering into the operation. Continuous gas-sampling vessels, coal and water meters, steam, water and gas temperature recorders are instruments whose practicability has been proved. With one man looking after these instruments, numerous records covering any desired period of time may be obtained. The results would determine the conditions necessary to effect the highest furnace and boiler efficiency. A CO_2 indicator and recorder would then be useful as an index of comparative operation and would be of material value only so long as the quality of coal and other controlling factors remained essentially the same.

W. D. ENNIS. Efficient combustion of fuel is a vital matter in the power plant of today, compared with which such a thing as the steam turbine is a mere detail. From an operating standpoint, such efficient combustion is largely a matter of air leakage, as shown by a recent test on one of the boilers at the Polytechnic Institute of Brooklyn. By carefully plugging up all the air-holes we could find, while making no changes in the method of firing, we increased the percentage of CO_2 in the flue gases from 4 to 11%. I estimate that this corresponds to an increase in boiler efficiency in the ratio of 57 to 35.

There are many reasons, some of which are mentioned by Mr. Uehling, for measuring the CO_2 rather than the oxygen. One of these reasons is that at reasonably good combustion efficiency the percentage of oxygen is so small as to be difficult to determine. Another reason is that stratification in the furnace results in the simultaneous presence of oxygen and CO and any deduction made from the presence of one alone would be unsafe. An average sample of CO_2 across the furnace, however, represents the facts. Although CO_2 measurements tell that something is wrong, they do not necessarily tell what is wrong. This may best be determined by observing the oxygen and the CO as well, giving an opportunity to check the results. If we disregard the moisture in the coal and the air, the constant

sum of oxygen, CO and CO_2 will be about equal to the percen
of oxygen in the air by volume.

I must dissent from the statement that a comparatively low
centage of CO_2 represents the best economy. This may be te
cally true, but it has been my unvarying experience that in pra
the percentage of CO_2 for maximum economy is the highest we
get. I believe we can not reach the point where efficiency
begin to decrease with increasing CO_2, and have even advo
paying the fireman a bonus for getting a high percentage of
It must be remembered, however, that an increase from 4 to
means $6\frac{1}{2}$ times as much gain as would an increase from 11 to 1

Automatic CO_2 instruments are satisfactory and reliable, but
are very expensive and we have been trying to develop some de
to replace them. We find that the sampling pipe gives conside
trouble, especially if the coal contains sulphur; when a depo
iron sulphate (?) is formed. This has been remedied by th
of copper pipes. One of the claims made for some of the auto
machines is that they give a constant indication of the actual
dition, yet in one plant we found the $\frac{1}{4}$-in. pipe line to measur
ft. to the nearest boiler and 180 ft. to the farthest. An inge
method for measuring the time required for the gas to travel
different boilers to the machine showed it to vary from $5\frac{1}{2}$ mi
to 6 minutes. In another plant a $\frac{3}{4}$-in. pipe was used to lea
gases 130 ft. to the intermittent sampling machine. It took
4 minutes to $16\frac{3}{4}$ minutes for the gas to reach the machine a
minutes to pass through it. I do not call that a constant indic
One of the firemen stated that when the fires were best the ma
showed the poorest CO_2. We have not yet given up the noti
judging everything we need to know about boiler furnace eco
from the temperatures at the furnace and stack.

It has been found that the water used in gas-sampling ma
absorbs CO_2 very rapidly and the practice of putting salt in the
does not decrease this absorption. By using a film of kerosen
the surface of the water it is possible to cut down the rate
about one-third and if the analysis is made quickly after taki
sample there is no loss. Some of the automatic sampling ma
confine the sample in water for about 24 hours and a determi
of the CO_2 under these conditions is far from accurate.

The ideal CO_2 recorder must be automatic, not delicate enou
the firemen to break, must be continuous and not intermittent
record and indicate its readings, and above all, it must not co

$0.25 per b.h.p. Such a machine should be placed in every boiler plant in the country.

WILLIAM KENT. We have on the boiler a steam gage to indicate the pressure of the steam, a gage glass to show the level of the water, and we should have additional gages for the temperature of the furnace and of the stack, as well as for the percentage of CO_2 in the flue gases.

I am surprised that Mr. Uehling did not mention in his paper the improvement in boiler economy that can be obtained by autographic registration of the furnace temperature. Fifteen years ago I employed a Uehling pyrometer with a Bristol recorder for this purpose and found that when the furnace temperature was in the neighborhood of 3000 deg., we had good economy, but when it was lower the economy was also lower.

Two other conditions of boiler economy are that the coal should be dry, and that it should not clinker and change its condition on the fire. These are even more important than any theoretical consideration regarding gas or coal analysis.

Recent literature on the subject of boiler economy places too much emphasis on the heating value of coal as determined by a calorimeter. Semi-bituminous coals are quite uniform in quality and always contain between 15,500 and 16,000 B.t.u. per lb. of combustible material, so that if we assumed an average value of 15,750 B.t.u. the maximum error is only about 1.5%, which is less than the probable error of sampling and of the ordinary calorimetric determination. With anthracite coal the heating value per pound of combustible does not vary over 1% from an average value of 14,900 B.t.u. and an ultimate analysis, or calorimetric determination, is therefore unnecessary. With these coals the important things are the moisture and the ash. With the bituminous coals of Pittsburg and the West the conditions are different and an analysis should be made to determine the volatile matter, and the heating value should either be calculated from the ultimate analysis or determined by a calorimeter. The most important indexes of boiler economy are a continuous autographic record of the temperature of the furnace and a continuous autographic record of the CO_2 in the gases.

I have used the explosion pipette quite frequently, but the results were of no value. I doubt the benefit of its use unless it is employed in connection with a more refined analysis than that made by the Orsat apparatus. When there is only a fraction of 1% of hydrogen

in a gas it is difficult to determine it with any approximatio accuracy.

D. S. JACOBUS. There is more to lose and to gain in the b house of the modern power station than in any other part of the p and the analysis of the gases is a move in the right direction should be remembered, however, that the gas analysis is only of the elements entering the problem. Mr. Uehling has shown the CO_2 reading is the important item, but it is also importa watch carefully for CO. Flue gas with from 12½ to 14% CO_2 only a trace of CO is quite a different proposition, from the s point of efficiency, from a gas with the same amount of CO_2 and ½ to 1½% of CO as the presence of this amount of CO means a siderable decrease in efficiency.

H. C. ABELL. One point which has not been brought out bly enough is that the hydrocarbons are often not properly bu Fifty per cent air excess will give about 240 cu. ft. of gases product of combustion. Assuming 15,000 B.t.u. per lb. of coa if only 0.7 of 1% or 1½ cu. ft. of CH_4 is given off unconsumed, will be a 10% loss in thermal efficiency. In some tests wh have made, the explosion pipette has been used to follow up the apparatus, and it has been found that a large percentage of th unaccounted for was due to unconsumed hydrocarbons. Ordin flue-gas analysis should occasionally be checked in this way dicate these losses. Oxygen should be used instead of air i explosion pipette. Enough hydrogen should be supplied to sure that ignition will take place, which otherwise might n account of the small percentage of combustible gas.

A. W. K. BILLINGS. We should not lose sight of the fac economy in the total cost of operation of the plant is more imp than efficiency of combustion. For example, with certain for chain grates it is very easy to get high CO_2, but the mainte expense is thereby increased, and other results occur which offset the saving in fuel.

The fact that CO_2 recorders in general are insufficient to bring in practice the expected economy has become evident in w the tropics where we have to deal with low-grade firemen and sive fuel. One cannot fail to be impressed with the facility which an ignorant fireman can "beat" a CO_2 recorder. Th

centage of CO_2 rises to a maximum and then drops if we keep on reducing the air supply. When the firemen are not subject to close supervision, they can, by unduly thickening the fuel bed and shutting off the draft, shirk their work and force the load on the other firemen. This can be done and a high CO_2 record can still be obtained, but at the expense of loss of efficiency and often clinker troubles as well. It is especially noticeable also that in many large and important plants the CO_2 recorders installed are used but little in regular operation.

It seems a mistake to confine ourselves to observation of the CO_2 alone in determining the efficiency of a plant. Small fractional differences in the air pressures in the furnace and flue passages give a more practical means of checking the performances of the firemen. In any case it is always necessary to make a practical study of how the fires should be handled and how the details of the plant should be managed to obtain the best efficiency. After this is determined it is immaterial whether we observe the percentage of CO_2 or adopt other means of watching the work of the fireman. Under conditions which preclude other successful methods of determining the efficiency of the plant I have tried the plan of observing the ratio of the drop in air pressure through the fuel bed and the drop to air pressure in the flue passages by means of a simple mechanical recording device and have found that observation of this ratio gives a very practical method of watching efficiency, as the apparatus is simple, requires no attention and gives instantaneous readings. The object aimed at in all cases is a practical means of watching the fire and those instruments which accomplish this end in the most practical manner will be the ones to come into practical use.

A. BEMENT. Mr. Uehling's paper is a valuable contribution to a subject of great economic importance, although it is probable that its economic value has been realized only to a very limited extent; in other words, what may be termed a theoretical, rather than a practical conception has prevailed. The CO_2 determination is an index to furnace conditions and as such should be considered as a very short form of gas analysis. It is the shorthand of gas analysis, and as with shorthand, the underlying matters are more or less elaborated and complicated. With the CO_2 determination, as with shorthand, one must learn its use, but when once learned it not only becomes of the greatest value, but is a necessity in the successful conduct of business. It is of the utmost importance, therefore, that the engineer

learn to make application of the CO_2 determination, or he will be unable to realize the benefit of a knowledge of its indication. The great advantage of the CO_2 determination is that it is the only method of gas analysis which may be continually and automatically employed, and which, at the same time, is susceptible of being recorded. It should also be realized that its practicability and convenience are much greater than the disadvantages due to not indicating incomplete combustion in the form of carbon monoxid and escaping hydrocarbons. That this disadvantage may be easily overcome is shown by the diagrams in the paper.

In brief, it may be said that in using the CO_2 determination in the management of fires, it is first desirable to produce uniformity of condition. When this has been done the amount of CO_2 should be regulated by an increase or decrease in the air supply, or by a greater or less thickness of fuel bed, which has the same effect as increasing or decreasing the draft. Also that if a charge of fuel to the furnace is followed by a decrease in the CO_2, it is a positive indication of serious loss in incomplete combustion, but if an increase in CO_2 follows the introduction of a fresh charge of fuel, it shows that the air supply has been in excess.

Mr. Uehling speaks of the most economical point of CO_2. From an academic standpoint the most economical CO_2 is the highest there is, the theoretical. It has been found, however, that under some conditions when the CO_2 gets beyond a certain point, which in some instances has been as low as 7%, that efficiency declines. So in such instances it might appear that 7% CO_2 is the most economical. But this ought not to be true. The explanation is that with some forms of imperfectly designed furnaces and with improper methods of coal feed the mixture between air supply and combustion gas and the evolution of volatile matter from the coal are so irregular or are brought about under such unfavorable conditions that the incomplete combustion losses are very great, so much so that they overcome the large saving due to decrease in excessive air. This is something which may well have serious consideration because the matter has not been very clear, there being a feeling that for some mysterious and undefined reason, the supposed advantage due to high CO_2 is unattainable, when, in fact, the remedy lies in correcting the condition of incomplete combustion.

O. C. Woolson. I have been greatly interested in studying Mr. Uehling's paper, and I believe that we must learn more fully to appre-

ciate refinements in steam making not only by installing CO_2 refinements but by a more intelligent appreciation of what the requirements are to obtain more perfect combustion of that particular fuel we are called upon to burn. The vast majority regard coal as coal, making no distinction between anthracite and bituminous other than to call the former hard and the latter soft, whereas there is both hard and soft coal in each of these classes and, whereas further, anthracite coal is entirely different in character from bituminous. To attempt to use a furnace of the same character for both kinds is evidence of ignorance and no CO_2 apparatus can rectify the results obtained.

What Mr. Uehling says in Pars. 27, 28 and 29 confirms what I have long felt, that to secure practical benefit from any CO_2 recorder it is necessary not only to have the apparatus properly installed, but to have its readings correctly interpreted, taking into account potent conditions which might exist, abnormal or otherwise, and which would prove a puzzle even to an expert, should he be lacking in a keen appreciation of such conditions. Unless some other solution can be offered for the many CO_2 recorders being out of use in different power houses, I am forced to the conclusion that we are attempting to establish an apparatus too refined for determining what is required to accomplish the greatest actinic value of our boiler plants, except for expert testing.

I believe that better results could be obtained by requiring the operating engineer to spend more time in the boiler room supervising the work of the fireman. Here again comes in the consideration of the different characters of anthracite versus bituminous. If the engineer is only experienced in burning anthracite coal he had best keep out of the boiler room till he has studied the bituminous element, and vice versa.

E. G. Bailey. In several places in the paper Mr. Uehling has referred to errors in the analysis of flue gas due to the water vapor present in the gas at the time of analysis. In Pars. 15 and 17 particularly he refers to the temperature at which the analysis is made and the corresponding vapor tension of water as being a factor which introduces an error into the analysis. Such a statement is very surprising and should not go uncorrected. There is, to be sure, an error introduced into gas analysis as usually made by an Orsat or other similar apparatus, if, during the operation of analysis, a change is made in the temperature or in the relative humidity of

the gas, but in usual practice the gas is collected and measured
water so that the relative humidity is 100% and the gas is
pletely saturated with water vapor at that temperature, regar
of whether the vapor came from moisture in the coal, the combu
of hydrogen, or from the water used in collecting and levelin
the analysis apparatus. With higher temperatures a higher v
tension of water naturally follows, and this vapor tension rem
constant as long as the temperature is unchanged, so that no
whatever is introduced from this source. Suppose that the ana
of a sample of flue gas was made at a temperature of 115 deg.
At this temperature the vapor tension of water is 2.987 in. of mer
or practically one-tenth of standard atmospheric pressure. A sa
of flue gas leveled up to the zero mark on the measuring buret
atmospheric pressure would contain 100% of gas and water v
combined. Water vapor would occupy practically 10% of
space and the dry gas but 90%. If this gas and water v
were then passed into the potash solution and all the CO_2
pletely absorbed and returned to the measuring burette, the re
would show a loss of say 10%, which represents the percenta
CO_2 in the flue gas. In reality, only 9% of dry CO_2 gas woul
absorbed in this case, while the corresponding proportion of v
vapor would be condensed and the total absorption would sti
proportional to the amount of CO_2 in the dry gas, regardless o
amount of water vapor present, so long as the vapor tension di
change from the time of one measurement until the other. No
would contend that correct gas analysis could not be made with
metric pressure of 27.92 in. of mercury, because the expansi
all the different gases contained in the mixture would be proporti
The same reasoning holds true if the increase or decrease in pre
is due to vapor tension of water in the gas saturated with it, so
as the temperature does not change.

In Pars. 25 to 32 inclusive, Mr. Uehling has discussed Figs. 1
which have been plotted from numerous individual flue-gas ana
These are useless since there are not sufficient data accompa
them from which to draw any useful conclusions. In each
four diagrams, Mr. Uehling has drawn two diagonals at such
that the sum of their ordinates at corresponding horizontal pos
of each is 21%. One of these is labelled theoretical oxygen,
the other is termed theoretical carbon dioxide. I think the
theoretical is entirely out of place in this case, and I also thinl
lines so drawn have absolutely no bearing upon the subject,

Mr. Uehling is attempting to determine the ratio of available hydrogen to the carbon in the fuel used in the various cases; or else, if this is known, these lines are so drawn that he could discern with some reliability the value of the analyses, many of which he has already criticized.

The points which Mr. Uehling has plotted from the various flue-gas analyses are not supposed to fall upon the theoretical lines, unless the fuel used were carbon. So long as the fuel used was not pure carbon, these lines cease to be theoretical, for so long as there is some available hydrogen present in the fuel there is inevitably a formation of water vapor which condenses during the usual method of analysis, and the nitrogen remains as a dilutent, as stated in Par. 17. In the case of some kinds of coal, the weight of available hydrogen is about 5 to 6% of the total carbon, and varies considerably with different kinds of coal. In the case of oil, the available hydrogen is 15 to 16% of the available hydrogen and carbon combined, while in natural gas it varies from 21% nearly to 25%. If Mr. Uehling had included some gas analyses from oil and natural gas, he would have found very great divergence from the so-called theoretical lines. The analyses might actually represent, however, the true theoretical relation which should exist between the various constituents of flue gas when burning the various kinds of fuel.

The difference between theory and practice will always continue as long as writers incorrectly define the theoretical or do not take into consideration all the factors which enter into the correct interpretation of practical results. Mr. Uehling's paper is sadly lacking in any data which would go to prove that a definite relation exists between the analysis of flue gas and actual boiler efficiency. The methods given in Appendix No. 1 are more laborious and indirect than necessary to make the calculations for the various losses, and he has also failed to take into account the variable specific heats of the gases, which seem to be so generally accepted among metallurgical engineers who have given close attention to the temperature and heat of gases in this connection.

THE AUTHOR. Mr. Bathgate's remark that a proximate analysis of the coal is insufficient to determine its real value is true. It is necessary to know all the elements of composition if a correct estimate of combustion is to be made, but in order to arrive at a practical solution we must not burden our problem with factors, the value of which is less than the probable errors of observation. That the carbon con-

tained in the ash is an important factor in boiler economy goes without saying; it is very small, however, in comparison with the chimney losses, and must be considered by itself.

Mr. Ennis emphasizes many of the points which I endeavored to bring out. His statement that we cannot reach the point where efficiency will begin to decrease with increasing CO_2 would imply that practically complete combustion can be attained with little or no excess of air. The fact that Dr. Jacobus and Mr. Abell, and no doubt others, who have not taken part in the discussion of my paper strongly dissent from this opinion, shows that more definite information is needed before valid conclusions can be drawn. The opinions formed are based on more or less numerous isolated tests in which the composition of the flue gas was merely an incident. To get at the true facts, it will be necessary to make a series of economy tests, in which the CO_2 is kept as nearly constant as possible in each test, and all other conditions as nearly constant as possible for all the tests. Such tests should be of not less than 10 hours duration; starting with 6% CO_2 in the first test, 8% CO_2 in the second, 10% in the third, and so on up to 16% or 18% CO_2 if possible. The CO_2 must be automatically and continuously recorded and complete analyses made as often as practicable. This series of tests should be made with the principal types of coal in general use. Until such tests shall have been made, Par. 21 and Par. 23 cover the case probably as well as our present knowledge permits.

Dr. Jacobus' statement that flue gas with from 12½ to 14% CO_2 and only a trace of CO is quite a different proposition from the standpoint of efficiency from a gas with the same amount of CO_2 and from ½ to 1½% of CO, is very true; but inasmuch as high CO_2 does not necessarily imply high CO, and since the loss due to CO varies inversely with the per cent of CO_2 (Par. 14), it would follow that a high per cent of CO_2 must be striven for. If considerable amounts of CO in flue gas occur with 40% excess of air there is something wrong.

When burning pure carbon 40% excess air gives 15% of CO_2, whereas with fuel in which the ratio of available hydrogen to carbon $\frac{H_a}{C} = 0.06$ if burned with 40% excess air will yield only 13% of CO_2. The higher the ratio $\frac{H_a}{C}$, the lower the maximum per cent of CO_2 that can be safely carried in the flue gas.

Mr. Kent expresses surprise that I did not mention in my paper the improvement that can be secured by autographic registration of the

furnace temperature. While it is undoubtedly true that the furnace temperature is a good index to boiler efficiency, it is not available for a continuous guide, because there is no pyrometer on the market

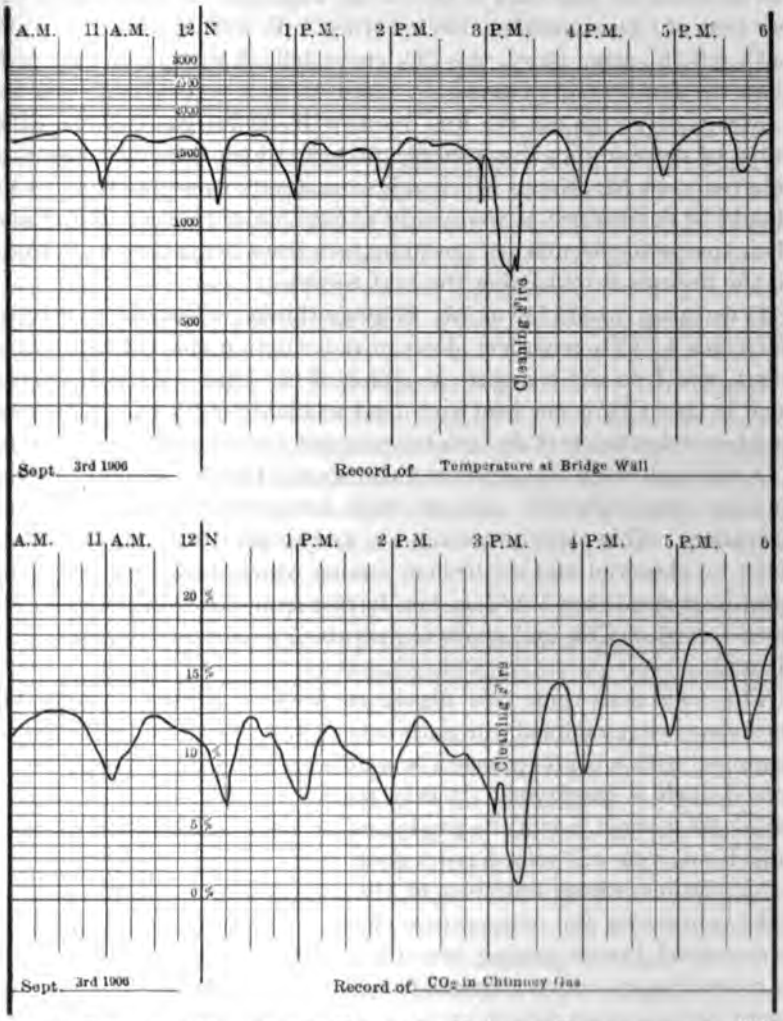


FIG. 5 RECORD MADE BY THE COMBINED UEHLING PYROMETER AND CO_2 RECORDER

that stands up continuously under temperatures reaching 3000 deg. and more. The pneumatic pyrometer will do it for a while, but not continuously.

Furthermore the per cent of CO_2 in the flue gas is a better index. The accompanying diagram (Fig. 5) shows a record made by the combined Uehling pyrometer and CO_2 recorder. The upper curve shows the temperature just back of the bridge wall, and the lower curve the per cent of CO_2 simultaneously recorded. It will be seen that while both tell the same story, the CO_2 curve tells it with more emphasis than the temperature curve.

Mr. Abell points out the loss due to CH_4 in flue gas and the difficulty of determining this element of loss, which difficulty was also referred to by Mr. Kent. While this constituent, as well as H and CO, should be determined as frequently as possible, their very nature and their spasmodic occurrence preclude them from being used as a guide to the fireman in obtaining the best results.

It certainly would be, as Mr. Billings thinks, a mistake to confine ourselves to CO_2 recorders alone in determining the efficiency of a plant, and I do not advocate anything of the kind. What I do contend is that CO_2 is the best and most available index to combustion and in connection with flue gas temperature to boiler efficiency. Low CO_2 and high stack temperature mean waste of heat. Complete combustion with high CO_2 and low stack temperature mean economic operation. This must be striven for, and to get it many other things must be observed and controlled, among which draft is perhaps the most important; but this does not detract from the value of a continuous record of CO_2 and stack temperature as a guide to boiler efficiency.

The fact that there are dishonest firemen, makes autographic recording instruments all the more necessary. Every boiler should be equipped with a draft recorder, or a differential draft recorder, where forced draft is employed. It may require some vigilance to detect dishonest firemen, but if the good ones are rewarded and the bad ones culled out, you will soon have a good staff.

Mr. Bailey whose criticism of the paper is appreciated, is quite right concerning the temperature effect of gas analyses. If the gas is saturated before passing into the absorption chamber, it cannot be more than saturated after the CO_2 has been absorbed and hence the vapor volume must remain proportional to the volume of the gas remaining.

His criticism of the diagrams, however, is quite off the mark. They bring out clearly very important relations existing between the constituents of flue gas. They show that there is a definite relation between the O and CO_2 and that no such relation exists between CO and

either O or CO_2. Fig. 1 shows that with dependable analyses, as those furnished by the Government tests, both the O and CO_2 diverge from the theoretical line by a definite angle. The degree of divergence depends on the value of $\frac{H_a}{C}$ as stated in Par. 26.

Fig. 4 shows that analyses against which good reasons appeared that they were faulty do not so converge from the theoretical line. The straight lines marked theoretical O and theoretical CO_2 are true theoretical lines for the products of combustion from carbon burned to CO_2 with pure air. To draw a theoretical line for every variation of hydrogen would be preposterous, nor would such lines bring out the relation between the principal constituents of the flue gas any clearer.

Mr. Bailey criticizes the formulae as being more laborious and indirect than necessary and in the same breath finds fault because the specific heats of the various gases have not been individually taken into account, instead of the average as I have done. This is quite inconsistent, since such a procedure would complicate the formulae very much without adding appreciably to their accuracy. Steam is the only constituent whose specific heat varies greatly from the rest and that is treated by itself in the formulae. If Mr. Bailey has or can develop a simple formula that covers all kinds of fuel, it would be welcomed by all concerned.

From Mr. Bement's discussion it becomes clear why the installation of CO_2 recorders has not always resulted in marked economy.

A CO_2 recorder does no more towards saving coal than a steam gauge does towards keeping up the steam pressure. To be of benefit all the conditions must be studied. If the CO_2 is low, the reason for it must first be found before the proper remedy can be applied. If the cause of low CO_2 is due to excessive air infiltration, for instance, and the CO_2 is increased by thickening the firebed, the loss due to CO and CH_4 may be greater than the gain due to the higher CO_2 so obtained. The CO_2 record gives notice that there is something wrong. It cannot supply the brains for determining the cause and applying the proper remedy. Without intelligent attention it is of no value; with proper attention and care it is a most valuable guide.

STEAM TURBINE TESTS

No. 1299*a*

TEST OF A 10,000-KW. STEAM TURBINE

WITH A BRIEF DESCRIPTION OF FEATURES OF CONSTRUCTION

By Sam. L. Naphtaly, San Francisco, Cal.

Member of the Society

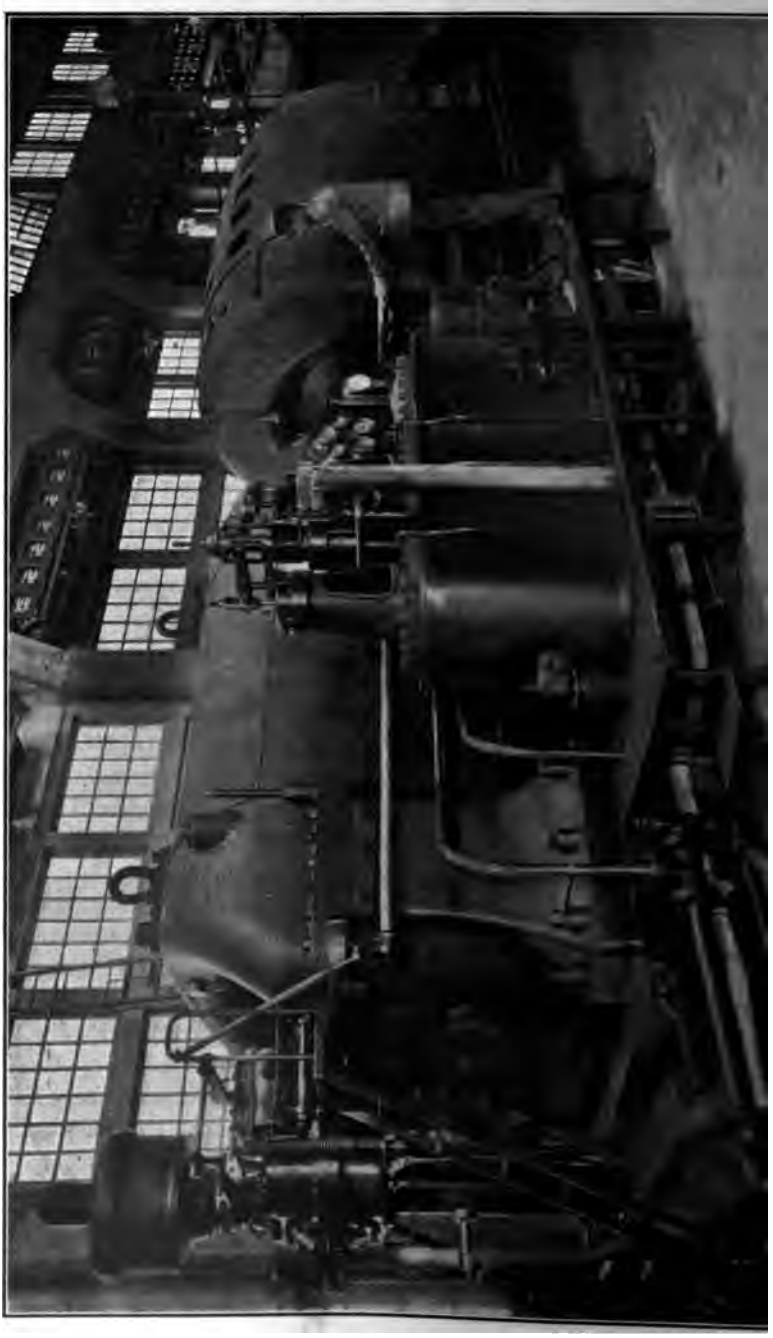
The steam turbine has experienced, as is quite universally known, the most rapid development of any form of prime mover, and its application has been extensively broadened within the last few years. Recent proceedings of this Society contain, in the paper on small steam turbines by Geo. A. Orrok and on tests of a 15,000-kw. steam-engine-turbine unit by Messrs. Stott and Pigott, useful data on small units and low-pressure turbine operation, respectively.

2 It is the intent of this contribution to record the attainment in the design and operation of a complete-expansion turbine of 10,000-kw. normal rating, installed in the latter part of 1909 in the main power station of the City Electric Company, San Francisco, Cal., under the author's management, and recently tested under the direction of J. G. White and Company, consulting engineers.

3 The object of the test was to determine the general steam consumption of the turbine unit under everyday operating conditions and further to determine whether the builder's guarantees of economy, generator temperature, etc., had been complied with.

4 The contract with the builder specified a turbine of 10,000-kw. normal capacity with an additional overload capacity of 50 per cent when operating with steam at 175-lb. gage pressure, superheated 100 deg. fahr. and with 28-in. vacuum, measured in the exhaust pipe and referred to a 30-in. barometer. Under the above conditions, operating at 1800 r.p.m., the guaranteed performance was as follows:

Presented at the Annual Meeting, New York, 1910, of The American Society of Mechanical Engineers.



Full load	10,000 kw.	14.3 lb. per kw-hr.
½ load	5,000 kw.	16.2 lb. per kw-hr.
1½ load	15,000 kw.	15.3 lb. per kw-hr.

The generator was designed for a 60-cycle, 3-phase current, and normal rating is 525 amperes per terminal at 11,000 volts, the tage being maintained constant at all loads by means of a Tirrill ulator. The generator is of the enclosed type and is provided h a direct-connected exciter, driven from the end of the main gen-tor shaft.

The generator was specified to have a temperature rise in any t above the temperature of the ingoing cooling air not exceeding following:

Full-load current, normal voltage, for 24 hr., 40 deg. cent.

1½-load current, normal voltage, for 24 hr., 50 deg. cent.

1½-load current, normal voltage, for 24 hr., 60 deg. cent.

The steam turbine is of the double-flow type, containing both ɔulse and reaction elements. The exterior of the unit, as installed the power plant is shown in Fig. 1, while Fig. 2 shows a longi-linal section of the turbine.

Certain features of construction of the turbine are as follows:

a Double-flow design, employing a single high-pressure impulse wheel centrally located. A division of steam between two similar and opposed intermediate and low-pressure reaction elements, one-half flowing through the annulus surrounding the high-pressure wheel, shown by arrows in Fig. 2. The large capacity and high rotative speed of the unit make it possible to utilize the double-flow construction, which has many obviously desirable features. Indeed, it may be said that for this capacity and rotative speed, the double-flow construction is imperative, since in a single-flow machine of the same capacity and speed the blade lengths in the low-pressure section will be so great as to preclude the possibility of sound mechanical construction or efficient steam distribution.

b Symmetry of cylinder structure, resulting from the double-flow design, favors the production of the casting with least initial strain, and permits of uniform distribution of temperature strains.

c High speed reduces the metal masses, ensuring greater homogeneity of casting with a resulting increased factor

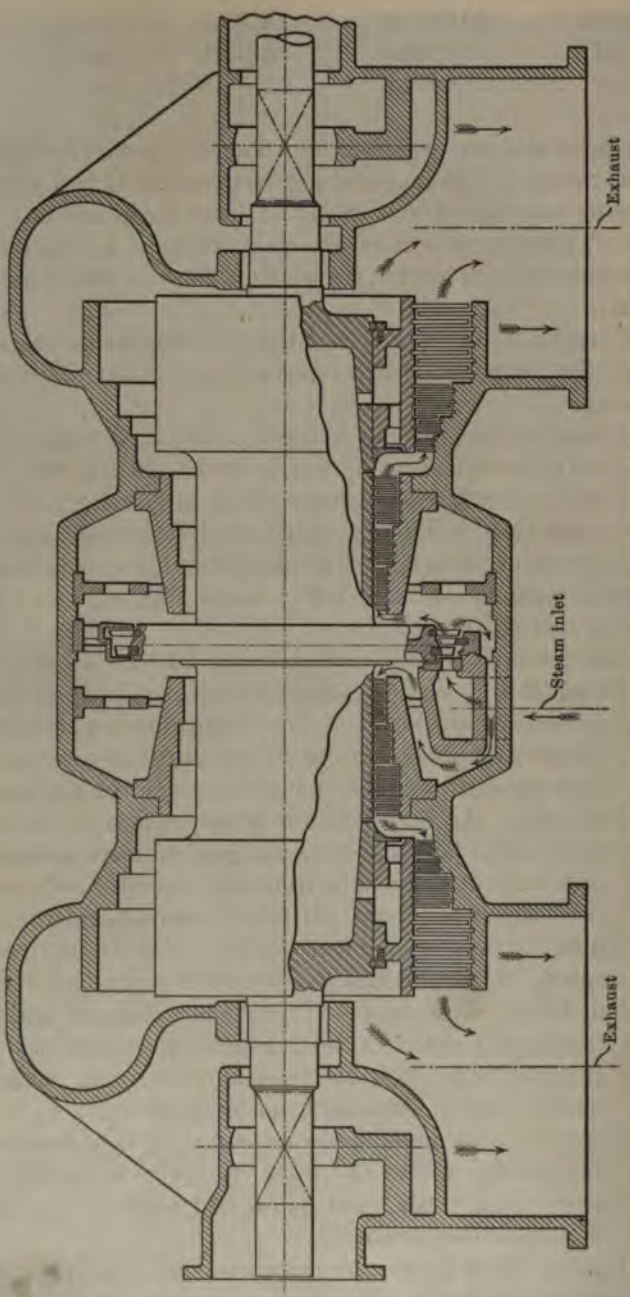


FIG. 2 SECTIONAL VIEW OF TURBINE, WESTINGHOUSE DOUBLE-FLOW TYPE

of safety, since the same peripheral speeds and centrifugal stresses virtually obtain as in the lower rotative speed designs.

d Turbine cylinder simplified with intermediate stationary element, cast separately and hence subject to less internal strains. Provision is made for the ready removal of these parts.

e There are no feet cast on the cylinder for supporting it on the bedplate. Instead, there are provided cast-iron chairs, two at each end, as seen in Fig. 1. The cylinder is carried by these chairs in a horizontal plane close to the axis of the turbine, the advantage being that with this construction the alignment of the coupling is less affected by temperature changes. The cylinder is free to slide on these chairs, permitting unrestrained expansion of the parts. In fact the turbine is not secured at any point except where it joins the generator inboard bearing pedestal, which, however, is rigidly bolted to the plate.

f The governing apparatus, while containing many improvements in detail, presents no particularly novel features. There are two governor-controlled inlet valves, each admitting steam to a group of nozzles; full load being carried on the primary valve alone. Overloads are maintained by a group of nozzles operated by the secondary valve.

9 These main valves and their operating mechanism are shown in detail in Fig. 3. They are hydraulically operated, oil under pressure being supplied by the oil pump driven by the turbine. The entire output of this pump is not necessarily used by the governor, the surplus escaping through a spring-loaded valve, which, together with that discharged from the valve-operating mechanism, furnishes the oil supply for the bearings. The operation of the hydraulic gear is, as is seen from Fig. 3, accomplished by the familiar relay and floating lever. Hitherto, it has been customary to construct the relay for a mechanism of this character without lap. If it does have lap, either negative or positive, the amount of this lap must be traveled before the mechanism can respond to the governor. A departure is here made from previous practice in providing the relay plunger with both inside and outside laps. The relay is kept oscillating a small amount by means of a cam connected to the governor linkage, sufficient to uncover slightly the ports at each oscillation, causing a correspond-

ingly slight motion of the main operating piston. The effect of the governor itself on this relay, is, of course, to change its plane of motion, and response to the least change in position of the governor weights is thus assured.

10 The condenser is of the Wheeler surface dry-tube type, equipped with primary feed heaters, turbine-driven centrifugal hotwell pump, and rotative dry vacuum pump. The condenser is located immediately below the turbine and is provided with two openings connecting with the exhaust at each end of the turbine. It contains 25,000 sq. ft. of 1-in. tube, No. 18 gage. A 42-in. cast-iron conduit, located so as to be submerged even at extreme low tide, conducts salt water direct from the bay of San Francisco to the plant. After being pumped through the condensers the salt water is returned to the bay through a suitable channel.

11 The turbine generator is of the builder's most recent four pole construction. The field is of nickel steel and is made up of two halves joined end to end by shrink links. Each half is integral with its shaft, which renders any hole for the shaft unnecessary and consequently considerably increases the strength of the revolving field. The field winding is done under heavy tension, which results in a very solid mechanical construction. The rotor is provided with a series of turbine fan blades, and the ends of the armature winding are covered by stationary end bells which, in addition to protecting the winding, serve as means of conducting the cooling air from the air ducts to the machine. This air is drawn from the conduits by means of the turbine blowers through the armature winding and is forced into the air gap, whence it passes outward through the armature laminations and is discharged into an exhaust air duct.

12 As this was the first generator of this design constructed, the City Electric Company insisted that tests be carried out by the builders before shipment, which showed an electrical efficiency at $\frac{1}{4}$ load of 92.2 per cent; at full load of 97.6 per cent and at $1\frac{1}{2}$ load of 98.2 per cent.

13 From the compromise tests which it was possible to make in the works, it was figured that the temperature rises at full load, 100 per cent power factor, would be 28 deg. on the armature laminations and 18 deg. on the field, by thermometer, the temperature rises by resistance being 22 deg. on the armature winding and 35 deg. on the field winding.

14 The tests by J. G. White and Company confirm these figures, their results showing that on a load of 5300 kw. at 89 per cent power

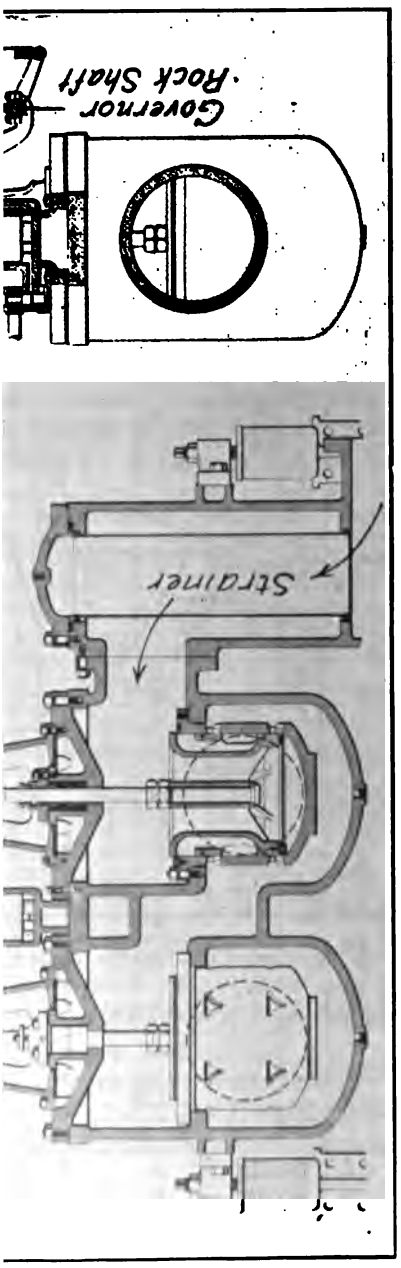


FIG. 3 GOVERNOR OPERATING MECHANISM

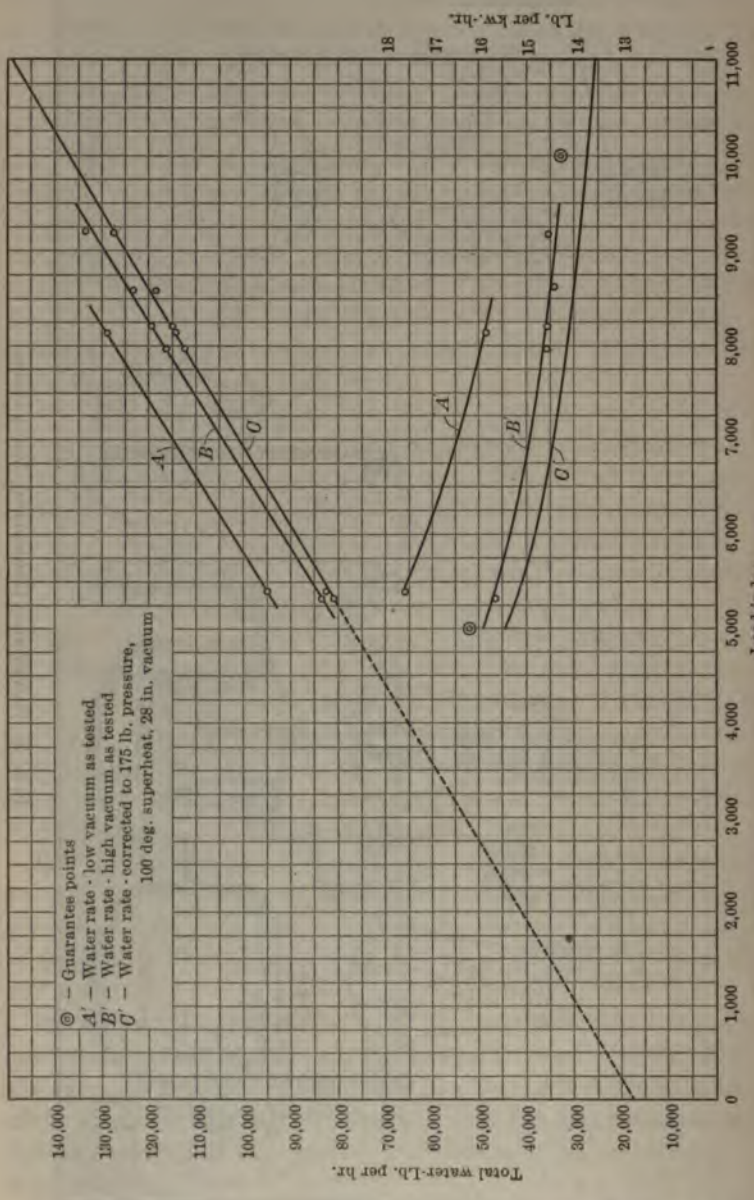


FIG. 4 ACTUAL WATER-RATE CURVES OBTAINED FROM TESTS

., the maximum temperature rise of the armaeg. On a load of 9300 kw., 89 per cent power v.a., the maximum temperature rise was configures are well within the guarantees.

TAILS OF TURBINE TEST

letails are given of the turbine test made after being shown by the curves, Fig. 4 and Table 1. the unit had to be maintained carrying the tests. During the high-load tests, it was the the station, so that observations had to be itions, with the load variations incidental to ıll, seven runs were made, two of which, *F* and ı for the purpose of establishing the effect of n this machine. In Table 1, both the Rankine

IMARY OF TEST OF 10,000-KW. TURBINE

LECTRIC CO., SAN FRANCISCO, MARCH 1910

Superheat, deg. fahr.	Vacuum 30-in. Bar.	Water per hour, Total, lb.	Water per kw-hr. as Tested	B.t.u. per kw-hr.	Rankine Cycle Eff. as Tested	Thermal Eff., per cent	Lb. per kw-hr. Corrected to 175 lb., 100 Deg. Sup., 29-in. Vac.	Remarks
58	28.28	116238	14.581	15378	66.9	22.20	14.11	High Vacuum
59	28.18	123542	14.427	15062	68.0	22.65	13.88	High Vacuum
60	28.10	119655	14.596	15414	67.6	22.10	14.04	High Vacuum
59	27.90	133672	14.572	15360	69.0	22.23	13.88	High Vacuum
54	28.34	83478	15.655	16493	61.8	20.70	15.21	High Vacuum
60	26.16	129181	15.855	16782	69.5	20.35	14.07	Low Vacuum
56	26.16	95120	17.611	18587	62.2	18.35	15.24	Low Vacuum

of the entire test varies but ½ of one per cent from the average of the g the test.

ciencies have been given in addition to the rate in pounds per kilowatt-hour, which is the usual performance of the steam motor. The thermal ıly the heat in the steam from the boiler, and is ıring results with other forms of prime movers, ıustion engines. The Rankine cycle efficiency, is sometimes called, is the more equitable meassteam motors, as it reckons with the work done

between the limits of steam leaving the boiler and exhaust entering the condenser. Taking the heaviest load carried, run *D*, the efficiency ratio obtained was 69 per cent including generator and field losses, which, I believe, is some improvement over results hitherto obtained for a complete-expansion turbine.

16 The performance of a steam turbine follows the Willans right-line law over a great range of its capacity, which gives a valuable check on the accuracy of the test points and reduces the number of necessary runs to a minimum. Furthermore, the performance of a turbine may be accurately predicted at loads beyond the range at which tests

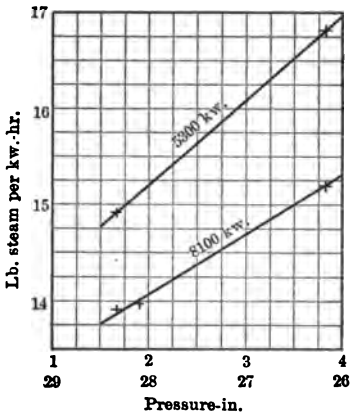


FIG. 5*a* TESTS FOR OBTAINING VACUUM CORRECTION

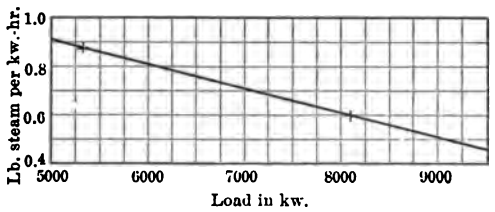


FIG. 5*b* CHANGE IN STEAM CONSUMPTION AT VARIOUS LOADS PER 1 IN. CHANGE IN VACUUM

have been run. Referring to Fig. 4, it is reasonable to expect that if a higher load had been available, the steam consumption would have further improved until the opening of the secondary valve. Allowing for a 10-lb. drop through the inlet valves, the load would have been approximately 11,000 kw., when, as seen by Fig. 4, a steam consumption of less than 13.7 lb. per kw-hr. would have been obtained, with an efficiency ratio of 71 per cent.

ed that slightly superior efficiency exists with
ad turbine unit reported by Mr. Stott at 72
it particularly making a remarkable showing.
ion basis, however, the San Francisco unit is
per cent in excess of the combined recipro-
, but it is obvious that this advantage in steam
by the advantage of the simple turbine unit
on of the reciprocating engine, the latter in-
st, greater floor space and cost of maintenance
ing down the unit while the reciprocator is
further complicating the system by use of
and high-pressure valves on the low-pressure

OF STEAM CONSUMPTION TEST

efore, it was necessary to test the unit while
consequently the loads of the turbine during
ubject to variations which probably may have

CORRECTIONS

; conditions specified by contract, namely 175-
eg. superheat, and 28-in. vacuum, could not be
; the test, correction factors had to be deter-
greement was reached previous to the tests as

cent change in steam consumption for 10 deg.
t, which is the correction factor commonly
or turbines.

½ per cent for 10-lb. change in pressure. (As
o reason for the full pressure not being main-
e were, however, insignificant.)

ne vacuum correction is affected by the
e turbine, the amount of the correction could
rmined in advance of the tests, and runs *F*
fore were made. From these and from the
it was found that 1 in. of vacuum affected
onsumption 3 per cent and 6 per cent at full
lf load respectively. These vacuum correc-
own in Fig. 5*a* and Fig. 5*b*.

20 All important readings were taken at 5-minute intervals, except in cases of energy output and water measurement, for which 15-minute integration proved adequate. Figs. 6 to 10 inclusive present graphically the principal logs of the tests. They show only small fluctuations of the pressure and temperature conditions, and consistent changes in load and steam consumption, insuring reliability of the average values.

21 The electric output of the unit was obtained with a General Electric polyphase wattmeter, checked by three single-phase integrating wattmeters, tested under the supervision of Frank E. Smith, consulting engineer, and Pacific Coast representative of the Weston Electrical Instrument Company. Its complementary current and potential transformers were similarly checked with standards.

22 Steam consumption measurements were made by actually weighing the water discharged from the surface condenser and delivered by a 5-in. single-stage centrifugal pump through 6-in. piping to a set of four weighing tanks. These tanks were 3½ ft. in diameter and 5 ft. deep. Each tank was on a 2000-lb. platform scale. The supply pipes and tanks were furnished with 5-in. quick-opening valves. Scales were tested and certified correct by the Howe Scale Company of San Francisco.

23 Tests were made for leakage of the cooling water into the condenser. As sea water is used for cooling, these tests were made by adding silver nitrate to samples of the condensed steam. No indications of leakage were found and hence no allowance was made for leakage.

24 The shaft glands were sealed by water taken from the condenser discharge before weighing and the leakage from outside of the glands was caught and measured. In this way no special allowance was necessary for gland sealing water. The stuffing boxes of the centrifugal hotwell pumps were sealed with water from the discharge. A small leakage occurred here, which was caught and added to the leakage from the main unit gland.

25 All pipes connected with the condenser or piping system, by which water might escape from the discharge or leak into the discharge water, were disconnected, blanked or arranged with two valves with an opening between for detecting leakage.

26 Observations were made of the pressure and temperature of the steam at the throttle pressures within the turbine at inlet, intermediate and low pressure points. The vacuum was indicated by a mercury column and the atmospheric pressure by a mercury barometer.

OF TEST DATA—RUNS A AND B

OF TEST DATA—RUNS C AND D

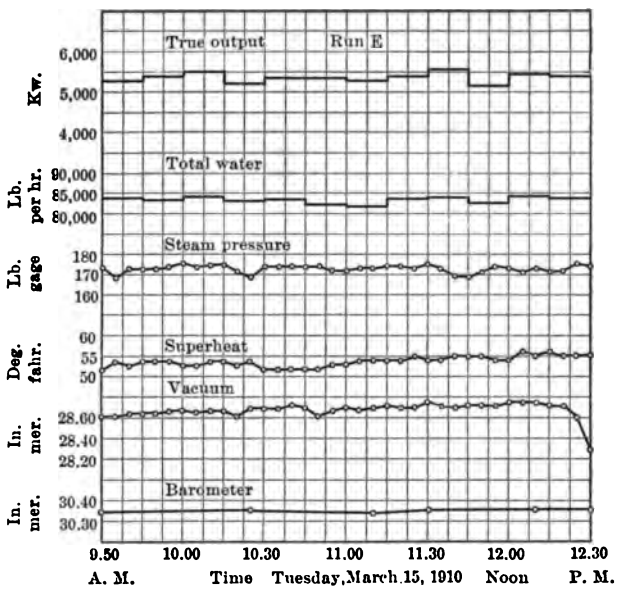


FIG. 8 LOG OF TEST DATA—RUN E

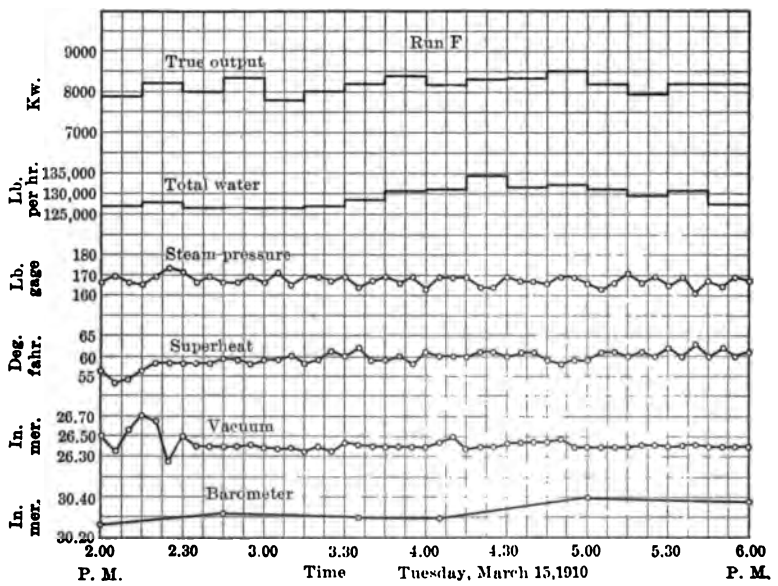
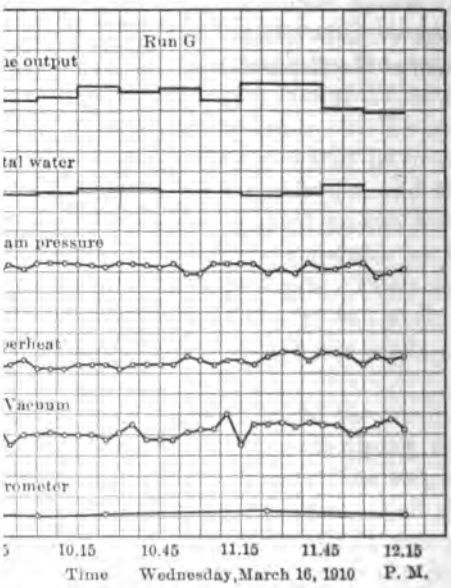


FIG. 9 LOG OF TEST DATA—RUN F

sted on a Crosby dead-weight testing machine. e throttle was 1 lb. high at the working steam temperatures were taken with a 15-in., ı-filled thermometer, made by Henry Green 'his thermometer was one of four new ones. greement of the four by check before the tests, gs were considered practically correct. The ed in a thermometer well in the steam pipe lve. The thermometer well was partly filled



) Log of Test Data—Run G

'emainder of space with oil. The thermome- he 400-deg. mark. As the steam temperature he effect of stem exposure was small. One to the temperature for this correction.

ge was a Hohman and Maurer instrument. with a $\frac{3}{4}$-in. pipe to both exhaust nozzles of g was provided with a valve admitting air to enser any condensation in the pipe. As the tube of small bore, 0.1 in. or less, allowance

was made for capillary depression of the mercury by adding 0.1 to the average of the readings.

28 The barometer was compared with the barometer of the office of the U. S. Weather Bureau and found to be 0.1 in. low.

29 The following is a summary of corrections applied to readings obtained during the steam tests:

Pressure of steam supply	Subtract 1 lb.
Temperature of steam supply	Add 0.1 deg. fahr.
Vacuum column reading	Add 0.1 in.
Barometer	Add 0.1 in.

30 It would encumber the paper to publish the complete detailed logs of these tests. The author will, however, be pleased to place them at the disposal of any interested members.

No. 1299*b*

)0-KW. TURBO-GENERATOR SET

F. H. VARNEY, SAN FRANCISCO, CAL.

Member of the Society

e years prior to 1908 the City of Oakland had been
nt for its electrical energy on the water-power
ission lines of the Pacific Gas and Electric Com-
to 150 miles from Oakland. In the year 1908
aat this service would necessarily have to be bet-
capacity, but also for regulation, and after con-
ry estimating, it was decided on the first day of
endeavor to have a turbo-generator set installed
ne for the Christmas holidays. Plans and speci-
ediately prepared and to hurry the work as much
y bonus and penalty clause was made a part of

y of the turbine seemed to be the one point that
as boilers, superheaters, steam piping, condenser
vere promised on time. The turbine was, however,
ı advance of promised shipment and the work
t delay until the unit was started and put into
December 18, 1908, thus making 171 days from
he plans and specifications to the successful oper-
n. It is interesting also to know that the station,
nerator, boilers, steam piping and auxiliaries, build-
verything necessary for a complete steam plant,
st $51 per kw.

h considerable satisfaction that the turbine was
s one of the driest years the water-power station
ced and the demand for power greatly exceeded
'ears.

nnual Meeting, New York 1910, of THE AMERICAN SOCI-
ENGINEERS.

34 The turbine was immediately put in parallel with the hydro-electric system, which consists of eleven water-power stations, three reciprocating-engine stations, and one gas-engine plant. It operated perfectly in every particular and soon demonstrated the superiority of this class of prime mover over reciprocating steam or gas engines, both in regulation and in maintenance.

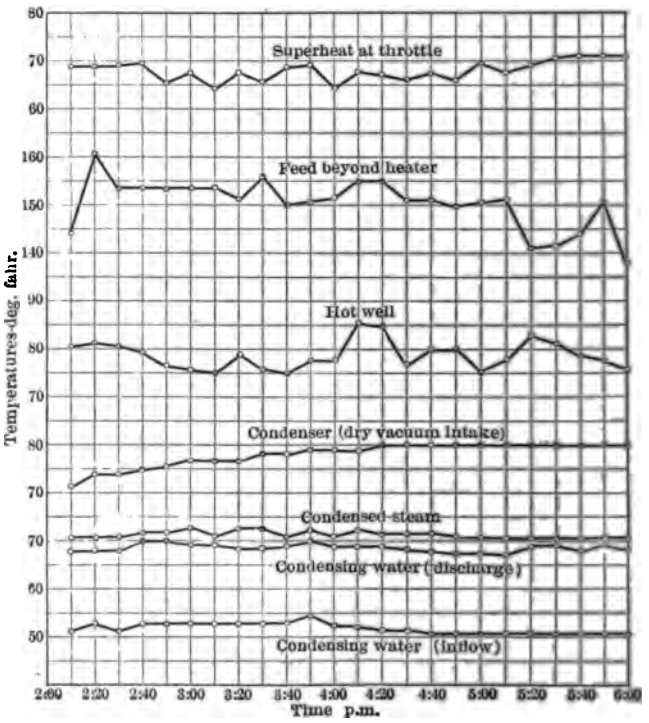
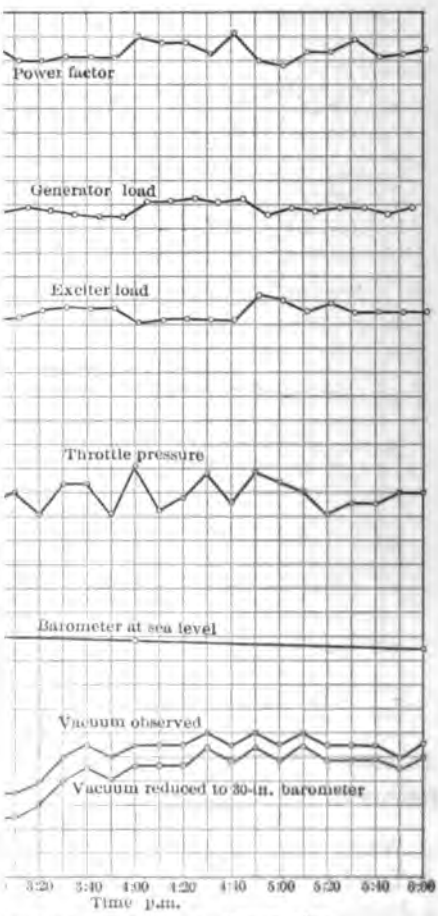


FIG. 11 LOG OF TEST DATA—FIRST TEST

35 The plant is situated on the Oakland estuary, between Grove and Jefferson Streets on First Street, distant about one mile from the center of Oakland. The estuary is a branch of the San Francisco Bay and has an ample supply of clean salt water from which circulating water for the condenser is drawn. A wharf was built into the estuary for the purpose of landing the fuel supply and as the Southern Pacific Railroad tracks adjoin the First Street side of the station, the location is considered ideal.

talled consists of a 9000-kw. vertical Curtis
ıum rated), Worthington condenser and
ght 754-h.p. McNaull water-tube boilers.
ısing what is known as the back-shot burners.
with superheaters for 100 deg. superheat.



.OG OF TEST DATA—FIRST TEST

nt need for the plant, the efficiency test was
ion had been in operation for 14 months.
t were as follows: The turbo-generator was
l commercial load, which was maintained as

nearly uniform as possible by the load dispatcher. Two runs of four hours each were made at loads approximating 7000 kw. and 9000 kw. The boilers were operated on the usual program, the number employed being adapted to the load carried. No attempt was made to obtain complete data regarding the economical operation of the boilers.

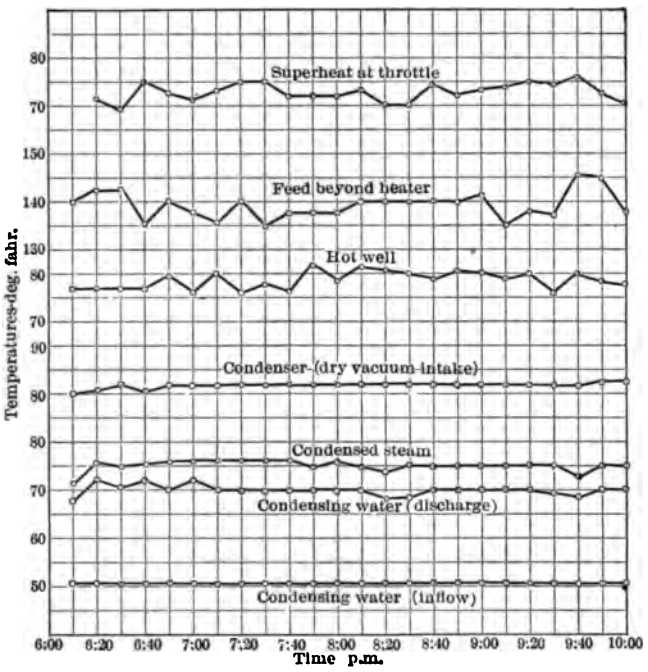


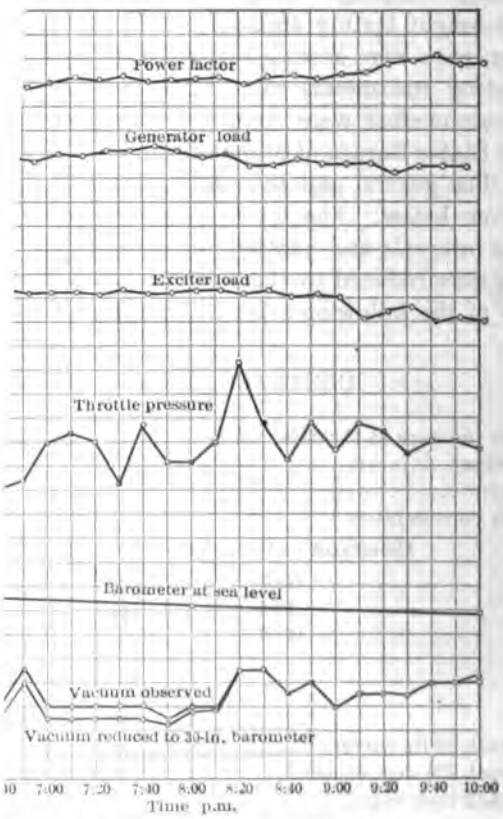
FIG. 13 LOG OF TEST DATA—SECOND TEST

38 In view of these conditions, it was decided to provide for the measurement of the following items:

a Water from turbine
b Total make-up and auxiliary water
c Power delivered by generator at switchboard
d Exciter output
e Pressures and temperatures required to complete and interpret the above observations.

39 Measurements of water were made by tank weighings with standard scales in lots averaging 1800 lb. to 1900 lb. and in accordance

ods recommended by the engineering societies
he power delivered by the generator was mea-
ıtallations of integrating wattmeters connected
ıe three-meter method for three-phase circuits.
ctrical readings and of all pressures and temper-



4 Log of Test Data—Second Test

t ten-minute intervals. Weighings of water were
ıs determined by the load. The level of water
and the condition of the weighing tanks at
f-hour period were also noted, thus providing for
t at any such period. Leakage tests of the con-
wet vacuum pump seal were made before and

after the test and a mean of the two values was used as the leakage correction.

40 All apparatus and instruments employed were carefully calibrated by reference to absolute standards or to others as near to them as possible. The scales employed were tested both before and after the run by the use of 50-lb. weights loaned for the purpose by the Fairbanks Company. All pressure gages were tested by the use of a dead-weight testing apparatus. The indications of the mercury vacuum gage were accepted as accurate without further test. The integrating wattmeters were calibrated before and after the run. All thermometers were compared with standards certified by the United States Bureau of Standards.

41 The general and economic results for each run as a whole are given below. Figs. 11 to 14 show the data worked up for ten-minute intervals and plotted on a time axis. The actual turbine results were reduced to the conditions specified in the contract, by means of the following schedule of corrections:

CONTRACT SPECIFICATIONS

1 Steam pressure at throttle.....175 lb. gage
2 Superheat.....125 deg. fahr.
3 Vacuum..... 28 in.
4 Steam consumption

Generator output (kw.)	Lb. per kw-hr.
5000	16.75
7000	16.40
9000	16.40

CORRECTIONS

1 For each 10 lb. pressure.....1 per cent
2 For each 12½ deg. superheat.....1 per cent
3 For each inch vacuum.....1.08 lb. per kw-hr.

GENERAL AND ECONOMIC RESULTS

1 Time, February 18, 1910.....	2.10 p.m. to 6.00 p.m.	6.00 p.m. to 10.00 p.m.
2 Total water with all corrections, lb.....	520,837	650,600
3 Average load, kw.....	6,922	8,775
4 Water from turbine as weighed (corrected for scales), lb.....	428,704	562,579

.....	−2,461	−2,568
lb.....	426,243	560,011
.....	16.06	15.95
g. fahr.....	78.1	81.9
water, inflow, deg.	52.15	51.0
g water, discharge, ...	66.50	70.0
densing water, deg.	14.35	19.0
d to 30 in. barometer, ...	28.30	28.03
.....	38.9	40.0

CORRECTED VALUES

p.m. to 10.00 p.m.

nt.....	− 4.13
.....	+ 0.48
ssure, per cent.....	− 3.65
.....	+ 0.03
lb.....	15.98
b.....	15.42

No. 1299*d*

ON STEAM TURBINES

e results given by Mr. Naphtaly in Table 1 per kw-hr. vary considerably from those and give the turbine a much lower heat k it should be credited with. I have tried e used both the old and the new steam tables o check the figures given in the table. Table sults.

SUMMARY OF TESTS ON 10,000-KW. TURBINE

MARKS AND DAVIS TABLES

Super-heat, Deg. Fahr.	Vacuum, 30 in. Barometer	Water per Kw-hr.	B.t.u. per Kw-hr.	Rankine Cycle, Ratio	Thermal Efficiency, Per cent
58	28.28	14.581	17035	66.8	20.04
59	28.18	14.427	16830	68.2	20.27
60	28.10	14.596	17017	67.6	20.05
59	27.90	14.572	16926	68.9	20.15
54	28.34	15.655	18274	61.8	18.67
60	26.16	15.855	18093	69.5	18.86
56	26.16	17.611	20075	62.2	16.99

of a turbine is the difference between the ring steam and the heat of the liquid in the d by the pounds of steam per kilowatt-hour. vith 168 lb. gage pressure, 59 deg. superheat, 1.427 lb. steam, we get a heat consumption or 16,830 B.t.u. per kw-hr. This result is er than that given by Mr. Naphtaly. The fficiency is 20.27 and not 22.65 per cent. s for Rankine cycle ratio check very closely e calculated.

M. E., Cornell University.

al Meeting, New York 1910, of THE AMERICAN NGINEERS.

D. S. JACOBUS. It would be interesting to have the views of some gas engine advocates in respect to the B.t.u. consumption obtained in the tests as compared with what they would expect under similar conditions for a gas-engine plant. The figures would indicate that the B.t.u. consumption per kw-hr. is low as was also the case in the tests of the oil-burning plant at Redondo, Cal., the results of which have already been reported to the Society. In these tests a kilowatt-hour was turned out at the switchboard with a consumption of about 25,000 B.t.u., based on the total heat of combustion of the fuel burned, all the oil burned for miscellaneous purposes about the plant being included, as well as that for carrying the boilers over a 4½ hr. layover period.

CHAS. H. PARKER[1] and I. E. MOULTROP. Referring to Mr. Varney's paper, it is interesting to learn that the steam turbine has operated satisfactorily when compared with a large number of water power stations and its service has been more satisfactory in regulation and maintenance than that obtained from either steam engines or gas engines. The engineers of the Pacific Gas and Electric Company are to be congratulated on the speed with which a 9000-kw. steam generating station was completely built and also on the very low cost of this station per kilowatt of capacity. If Mr. Varney will state briefly in his closure how this very low cost was obtained it will add much interest to his paper.

The author states that the test showed the water rate of the turbine to be inside the manufacturer's guarantee, but it would seem that the actual performance was not especially creditable to a modern Curtis turbine of 9000-kw. maximum capacity. Of course, the vacuum during the test was not especially good and with injection water of 51 deg. to 52 deg. fahr., it should be possible to reduce the absolute back-pressure reported in the test by about 1 in., which would improve very much the water rate of the turbine.

The superheat of 70 deg. to 75 deg. on the maximum load test is also rather low for the best results. Experience has proved that 150 deg. fahr. of superheat is safe for superheaters and piping and this increased quantity would better the water rate some 6 per cent.

Either or both of these changes might have increased the investment by a small amount. However, a gain of about 1¾ lb. in the water rate per kw-hr. would seem to be easily obtainable and would justify

[1] Boston Edison Co.

charge. It is not usual for a maximum-
sults than a normal-load test. The General
ee usually calls for about ½-lb. poorer water
normal load.

ributed some very valuable data upon the
r turbine, a type of machine about which
s been published. The unit is large, having
0 kw. and an overload capacity of 50 per
perature on the generator is only 60 deg.
at 1½ load, this unit might well be given a
nuous capacity. It seems from the test that
especially at the low superheat and com-
sed during this test.

curve is very instructive, as it shows a very
se of vacuum, thereby differing widely from
shape of the vacuum correction curve would
f increased vacuum at overloads would be

hat the requirements of the station would
; carried to full overload of the turbine, as
o see how the opening of the secondary
t line of total water consumption, and a
in vacuum at overload would give a third
would be most instructive.

Curtis turbine in a plant of the Great West-
Oakland, Cal., was tested at 3464 kw. load,
oilers, 127.4 deg. superheat, 1.17 absolute
mercury. The water rate was 13.62 lb. per
he unit this seems very good.

n of the Boston Edison Company, a 5000-
ne unit tested in 1907 showed the following:

.....	2558	5195	7526
.....	173.0	173.7	169.7
.....	149	142	134
essure, in. mercury	1.13	1.18	1.35
.....	15.24	13.57	13.73

en tested once a month since being installed
ual water rate came with the highest super-
follows: 5095 kw. load, 170.4 lb. steam
.1 deg. fahr. superheat, 0.52 in. of mer-
lb. of water per kw-hr.

The water rate of this test, corrected to standard conditions, is slightly poorer than in the test made at the L Street Station, so that any possible error in the latter test is in the direction of making the water rate too poor rather than too good. These figures seem to show conclusively the advantage of high superheat and vacuum, at least on the impulse type of turbine. It is the overall efficiency of the plant for which engineers should strive and this is a question of the greatest output for a pound of coal. Of course the investment needed to secure the increased efficiency must be justified by the saving in operating.

A glance at the correction curves used with the various units spoken of is most interesting, as they suggest the possibilities of the various kinds of turbines under different conditions of superheat and vacuum:

Type	G. E. Vert.	West. D'ble-Flow	G. E. Vert.	G. E. Vert.
Company	Pac. G. & E.	City Elec. Co.	N.Y. Edison	Boston
Station	Oakland	San Francisco	New York	L Street
Maximum capacity of unit, kw	9000			
Normal capacity of unit, kw		10,000	8000	5000
Corrections for pressure, 1 per cent for every	10 lb.	20 lb.		10 lb.
Superheat, 1 per cent for every	12½ deg.	10 deg.	12 deg.	12 deg.
Vacuum, normal load, per in	1.08 lb.	0.45 lb.	0.985 lb.	1.15 lb.
Vacuum, ½ load, per in		0.91 lb.	1.35 lb.	1.60 lb.

These figures would indicate that the impulse turbine received more benefit from an increased pressure than the combined impulse-reaction machine, which is very curious, to say the least, as the high-pressure elements are of the same type. The benefit from an increase in superheat is marked in both the types, with the advantage slightly in favor of the double-flow type. The benefit from an increase in vacuum is very much less in the double-flow combined impulse-reaction turbine than in the straight impulse turbine, especially at the heavier loads, which is 42 per cent as much at full load and 62 per cent at ½ load.

The designer should provide for a moderately high superheat and as good a vacuum as the inlet water temperature will warrant, and then the operating engineer should continually maintain the condensing

s to get the best vacuum obtainable with the . This is true with both types of turbines y true of the straight-impulse turbine.

Society is to be congratulated on the papers Varney, which place before the membership nodern types of power-generating apparatus. onnection to compare these results with those ations, published tests of which have been ; few years. I have had made such a table, n the same basis, using the new Marks and have neglected the Rankine cycle efficiencies, fficiency of the generator and the mechanical are not given, and cannot be easily obtained.

ECONOMY TESTS OF STEAM TURBINES
ARKS AND DAVIS STEAM TABLES

	Load, Kw.	Steam Pressure, Lb. Abs.	Superheat	Vacuum	Steam, Lb. per Kw-hr.	B.t.u. per Kw-hr.
....	4179.6	179	289.3	29.19	11.95	15665
....	5164.1	207	125.2	29	13.15	16122
....	10816	190	147	29.47	12.9	16206
....	3150	185	225	28.5	13	16352
....	5195	179.5	142	28.8	13.52	16578
ing-						
....	8563	183	59	28.18	14.427	16850
....	9830	192.2	96	27.31	15.15	17778
....	5128	176	193.7	28.47	14.32	17790
....	8880	192.5	108.5	28.1	15.05	17940
....	8775	194	72.95	28.03	15.95	18735

compare the various machines on the basis of at the throttle valve, and to credit the turbine he heat turned back into the feed water sys- nperature. This fact is what power producers B.t.u. so calculated represents what they are

3 I have used in the actual test result, pounds nour, vacuum, superheat and steam pressure ntract conditions.

ie experience obtained from over 2000 steam uld now reveal the operating conditions and

design which realizes the highest final efficiency. Uniformity of operating conditions has already become evident, and very probably a general accepted type will eventually be prevalent. These facts have already been the subject of both favorable comment and noteworthy action in this direction.

Mr. Naphtaly is to be commended both for having selected moderate working conditions by means of which he obtains the highest ultimate economy and for having endorsed an increase in rotative speeds which obviously conduces to higher efficiencies.

Fig. 15 demonstrates that 100 deg. fahr. is about the upper limit of superheating that may be profitably employed. In constructing this diagram, care has been taken to make all of the assumptions favor high superheat as much as possible, so that I believe it presents the most optimistic view of the subject.

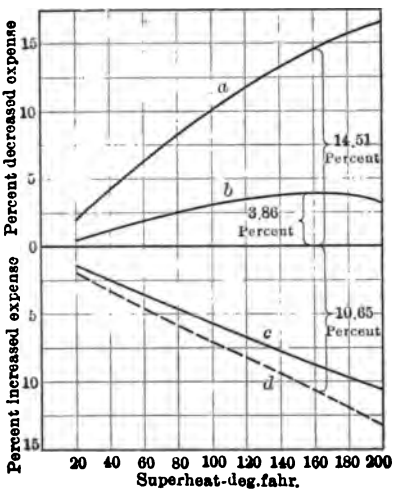


FIG. 15 INCREASE OF EXPENSE WITH INCREASE OF SUPERHEAT

Full load operation 175 lb. steam pressure, 210 deg. feed water temperature, C_p values from Knoblauch & Jakob. Investment and maintenance charge pro-rated assuming equal capital and fuel expense.

a Per cent decrease in turbine water rate
b Net economic gain not allowing for increased radiation losses
c Increased heat addition to steam
d Total increased expense, including investment and maintenance charges

While the water rates which Mr. Naphtaly obtained with his turbine (14.57 lb. as tested, and 13.88 lb. as corrected) somewhat exceed other steam consumptions that have been recorded, there has, nevertheless, been established a new mark in the efficiency of conversion of

the available thermal energy between the throttle and exhaust pressures into electrical energy at the switchboard: viz., 69 per cent as referred to the Rankine cycle.

Very few of us realize, initially, the true relative effect of different operating conditions. Any changes in steam pressure, vacuum or superheat, as affecting the available energy, is shown at a glance in a temperature-entropy diagram as reproduced in Fig. 16. For example, with initial conditions of 190 lb. and 100 deg. fahr. superheat, ½ lb. reduction in pressure at the exhaust end from 28 to 29 in. vacuum, increases the available energy as much as the addition of over 100 lb. at the inlet of the first stage.

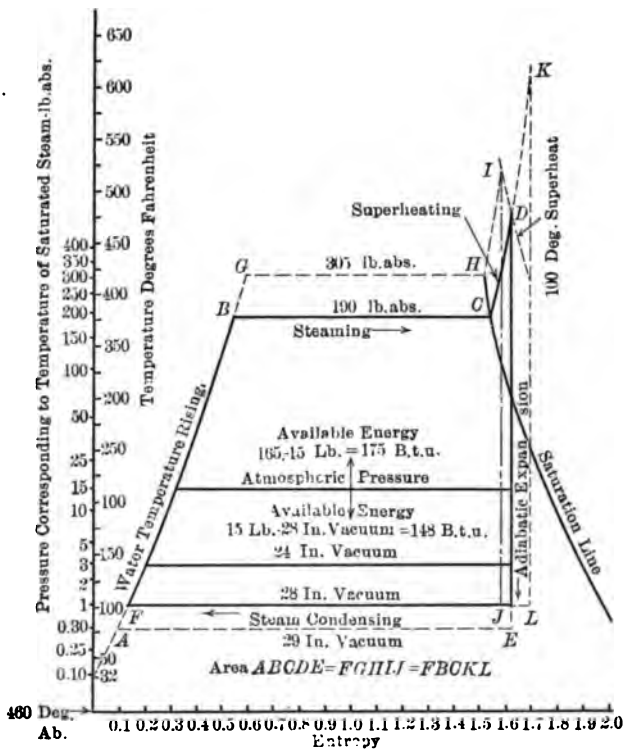


FIG. 16 TEMPERATURE-ENTROPY DIAGRAM

The above efficiency, as already noted, has not been equalled in any other published test. It is to be remembered that this percentage includes all armature and windage losses of the generator, as well as the field losses which are commonly omitted. Table 4 gives the best American and European turbine performances that are on record.

Although some show lower steam consumption, due either to a higher superheat or to vacuum, or to both, in every instance the efficiency ratio falls considerably below that of the City Electric turbine, which is truly complimentary to American development. The extrapolated result of 71 per cent at maximum load on the primary valve stands out even more prominently.

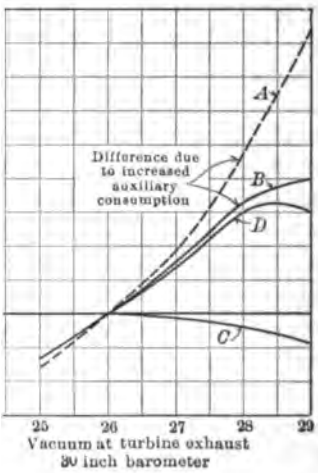
TABLE 4 STEAM CONSUMPTION AND EFFICIENCIES OF STEAM TURBINES

	Type	Name	Load, Kw.	R.p.m.	Boiler Pressure, Lb. per Sq. In. Gage.	Superheat, Deg. Fahr.	Vacuum, In. Mercury, 30 In. Standard	Water Rate, Lb. per Kw-Hr.	Rankine Cycle Efficiency*	Authority
American	Reaction Westinghouse	New York Edison	9870	750	177.0	97.0	27.31	15.0	67.3	Operating Co.
		Brooklyn Rapid Transit	11466	750	177.0	106.0	28.15	14.45	65.72	Operating Co.
		City Electric Co., San Francisco, Cal.	9173	1800	167.0	59.0	27.9	14 57	69.0	J. G.White & Co. Tests
	Impulse Curtis	New York Edison	8880		177.8	108.5	28.1	15.05	63.1	Geo. A. Orrok
		Commonwealth Edison	10186	750	176.0	147.0	29.47	12.9	62.1	Consulting engineers
		Pacific Gas & Elec.	8775	750	179.3	72.95	28.03	15.95	61.0	F. H. Varney
European	Reaction	C. A. Parsons, Carville	5059	1200	194	92	29.27	13.35	62.9	Z. d.V.d.I.† 1907, p. 1122
		C. A. Parsons, Chelsea	6000	1000	190	140	28.00	14.09	65.8	Test result
		Brown-Boveri, Frankfurt	3522	1360	142	136	28.92	13.68	65.8	Z.d.V.d.I. 1908, p. 516
	Impulse	Escher Wyss Co., Essen	5118	1025	146	158	27.63	15.16	65.1	Z.d.V.d.I. 1908, p. 1436
		Escher Wyss Co., Turin	3540	1485	172	105	28.29	15.10	64.4	Z.d.V.d.I. 1908, p. 1437
		A. E. G. Moabit, Berlin	3169	1500	170	217	29.19	12.74	67.5	Z.d.V.d.I. 1907, p. 386
		A. E. G. Rummelsburg	4239	1497	173	285	29.19	11.90	65.1	Z.d.V.d.I. 1909, p. 762
		D. Howden & Co., Manchester	7520	1000	184	133	27.55	14.50	67.0	The London Engineer, 1909, p. 462
		D. Howden & Co., Manchester	6383	1000	188	137	27.44	14.30	67.6	The London Engineer, 1909, p. 462

*Peabody's Steam Tables, 1909 Edition, used in calculating Rankine cycle efficiency on kw-hr. basis.
†Zeitschrift des Vereins deutscher Ingenieure.

It is believed that the efficiency ratio consistently improves until 100 deg. fahr. superheat is exceeded, when further delay of the dew point of occurrence of saturation is offset by the greater amount of heat in 1 lb. of steam passing out to the exhaust. Hence it is not improbable that the turbine would have accomplished a slightly better record with additional superheating, 60 deg. being the average throughout the test. The effect of vacuum is more indefinite and is subject to the areas and angles provided in the final stages of the turbine.

minately stated that the higher the vacuum
ıt results. This is plainly a narrow perspec-
ption of the condenser auxiliaries is thus en-
er temperatures fall off very rapidly with the
shown by the standard steam tables, and the
nd power required by the air and circulating
ionately greater. There is consequently a



GE OF DIFFERENT VACUA ON ULTIMATE PLANT ECONOMY BASES

ace condensers supplied with average injection
am conditions 175 lb., 100 deg. superheat. Most
auxiliaries selected for each vacuum to give best
veen investment and fuel economy pro-rated on the
arges being one-half of fuel expense burning $3

ıe turbine
t fuel consumption
fixed charges and maintenance) of obtaining the

ıent

ment in the turbine fails to exceed the in-
d by the auxiliaries, and in the latitudes we
nerally find the most economical yearly aver-
ven 28 in. and 28.5 in. (referred to 30 in. bar-
ı the source of water supply.

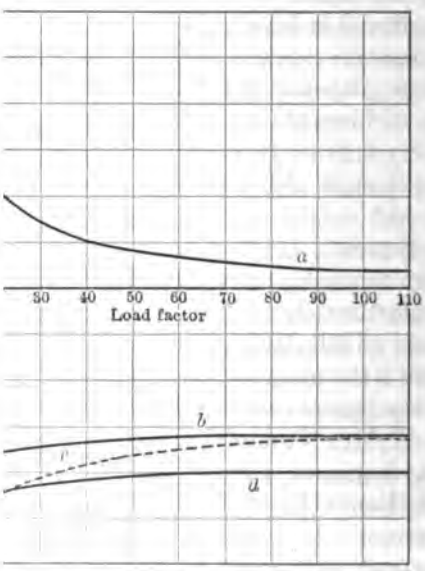
This is apparently the upper economic limit when the falling off in vacuum with periodic fouling of tubes is considered. Moreover, the deductions were based on uniform efficiency ratios of the turbines for all vacua, which evidently encourage a higher limit. It is to be noted that all the station auxiliaries were accounted for in deriving the best heat balance. Although larger units than those treated in Fig. 17 may have slightly increased advantages owing to a better arrangement of auxiliaries, they do not tend to produce improved plant economies beyond the limits already expressed when all modifying conditions are borne in mind. For this reason, the order given in Table 3 is not an equitable reckoning, since the vacuum factors are disregarded.

I am at variance in opinion with Mr. Moultrop in regard to the merits attached to the effect of change in vacuum on the economy of the different types of turbines. I do not believe the manner in which he has presented this phase portrays the essential considerations. It is patent that the reaction and impulse turbines may be readily designed for the same efficiency for any given vacuum whatever, virtually placing them on a parity in so far as realising on a fixed high vacuum is concerned. Regarding fluctuations in operating conditions, his comparison correctly shows that the straight-impulse machine with the fewer rows of blades both gains and loses most with changing vacuum, and consequently is more sensitive to such variations and will more rapidly decline in efficiency if the auxiliary station equipment is not maintained up to the original standard.

Doubling the rotative speed reduces the steam consumption from 4 per cent to 6 per cent, depending upon the size. In 1000-kw. turbines of 3600 and 1800 r.p.m. under U. S. Government tests, a difference of 4.5 per cent was shown. Large turbines, such as those under discussion, would probably show somewhat better results.

While fuel economy is an important factor of the total cost of power, investment and operating expenses must also be reckoned with. Fortunately I have been able to obtain what I believe may be considered conservative installations and monthly operating costs from Mr. Naphtaly's plant. These results plainly indicate efficient management, both in construction and subsequent operation. The entire station consists of two 2500-kw., and one 6000-kw. turbine, in addition to the 10,000-kw. unit. A typical monthly payroll was $3565; oil, waste, supplies, water and maintenance material averaged for three months, $769; the corresponding oil-fuel consumption, for the entire station 20,800 bbl., and the output, 4,908,800 kw. The smaller units

wages, and therefore only three-fourths, or
le on the base of the use of large units.
addition provided by the installation of the
cost to the City Electric Company may be
.t $339,413 or $33.94 per kw., including build-
rs, piping conduits, oil storage and burning
and electrical apparatus—in fact, everything
state up to and including the switching gear.



OF POWER AT VARIOUS LOAD FACTORS

plant oil fuel $33.94 per kw. installed
at $0.60 per bbl.
nt coal fuel $3 per ton
it $0.78 per bbl.

pense per unit generated at various load fac-
led in Fig. 18—four mills, total, with the low
with a higher oil cost, which is certainly excel-
rally affects the investment by the elimination
andling apparatus with corresponding heavy
tails less boiler-room labor. A reduction (Fig.
ns has, therefore, been carefully made on the
al at $3 per ton delivered, fully accounting for

the various items involved. The investment would hardly be increased more than 30 per cent at the utmost for coal-handling machinery and bunkers.

The low total cost of a complete-expansion turbine, excluding investment and cost of labor, settles the question definitely as to the advisability of introducing a combined engine-turbine unit in a new station to accomplish a small saving in fuel.

Another feature of interest refers to the floor space occupied. By employing the higher speed of 1800 r.p.m., instead of 900, the unit has been reduced in length about 17 per cent. Mr. Naphtaly developed his plans providing for two rows of turbines in the engine room, having them alternately faced with respect to one another. The 10,000-kw. turbines of the type described demand an engine-room floor space of only 0.18 sq. ft. per kw. of normal capacity installed, which figure it is thought also constitutes a new record.

R. J. S. PIGOTT. It is fortunate that manufacturers and owners of turbines are becoming more broad-minded about publishing data on tests. Unfortunately, many of these are rendered less valuable by the omission of full data, particularly the bases of computation. A case in point is the computation of B.t.u. per kw-hr. and efficiencies (Table 1). These figures could not be checked from the data in the paper.

In Par. 17 Mr. Naphtaly compares his machine, which is really 15,000-kw. maximum rating, with the combined unit at the Interborough Rapid Transit Company's 59th Street Power Station. His comparison is based on 60 deg. superheat on his machine against saturated steam at the 59th Street Station. The thermal superiority of the combined unit is 8.5 per cent on this basis. There is nothing, however, to prevent the use of superheat on the combined unit. A fair basis is using superheat in both cases.

With 60 deg. superheat, the 59th Street unit water rate at best load would be 12.3 lb. per kw. instead of 13.2 lb., which brings the advantage of the combined unit to 13.5 per cent, about the same as given in the paper[1] by Mr. Stott and myself on this unit. But taking the conditions just as they stand, if the units are operated on normal load the saving on coal and water by the more economical combined unit, even on saturated steam, averages approximately $80 per day. The extra attendance is $8 per day; the additional fixed charge $12 per day; and the maintenance charge $7 or $8 per day over that

[1] Trans. Am. Soc. M. E., vol. 32, p. 69.

installation. This still leaves a very sub-
the combined unit. These figures are based
naximum rating for the high-pressure turbine
combined unit, a somewhat conservative fig-
considerable advantage of the low-pressure
hly improbable that new plants of the com-
since the high-pressure turbine is improving
y.
teresting if Mr. Varney had itemized his cost
evidently based on maximum rating. When
ıg apparatus and absence of land charge is
, the total cost figures nearly up to the aver-
: plants.

ıe results reported in Mr. Varney's paper are
worse than the results which Mr. Moultrop
ın turbine, which is identical with the machine
paper, two or three of which have been tested
The machine in question was tested under
ıaving been in operation about a year and the
ble errors in such tests are very well known.
y's paper shows a cross-section of the West-
ich the test was made. The peculiarity of
naturally be expected at such a high speed,
ıe discharge steam at the low-pressure end.
:s are carried by a drum which is under con-
s own weight, and the load which the buckets
must be conservative to prevent loosening
ıld result in unsteady running. To avoid
ıas been made very small in order to reduce
ınd a rough calculation indicates that with the
00 kw. the steam was issuing from the final
ut 1400 ft. per sec., which is equivalent to a
ı the total energy of the steam. This condi-
l by the dimensions, but is shown by the rate
uum reported. When these facts are con
that this machine would give a very much
ıter load is easily seen to be fallacious. This
ın good vacuum should be rated at 7000 kw.
ı with a suitable proportioning of the upper
ould give very good economy at such a load

The economy reported is extremely good in all the tests; probable that many of the readings are fairly correct, although I am inclined to doubt the one that gives 69 per cent at heavy load because the dimensions do not seem to render it possible. It may be that this test is as much favorable to this machine as the other one was unfavorable to the Curtis.

The question of the value of vacuum is a very important one to all users of most turbines. It is easy to build machines suited to low vacuum, and if no regard is paid to efficiency, the ratings may be increased indefinitely, thereby reducing the cost.

If the dimensions are proportioned conscientiously for high vacuum, many difficulties are encountered with high speed. Mr. Varney's machine gained over 6 per cent in water rate for a variation of 1 in. of vacuum when operated at full load, while Mr. Naphtaly's machine gained 3 per cent. Any turbine can be proportioned for a high degree of Rankine efficiency with low vacuum, but as the efficiency curve falls we fail to get a full compensation for the falling temperature of the condensed water. In most good turbines the limit of desirable vacuum lies above 29 in. Mr. Naphtaly's machine at 28 in. vacuum and 8000 kw., should be a highly efficient unit, but with higher vacuum it should be relatively inefficient and its efficiency would also decline rapidly with high loads if the vacuum is high.

It is often stated that records of turbine tests in Europe are better than those in this country and that the Curtis machines made by the A. E. G. are better than American Curtis machines. In point of fact, the A. E. G. turbines at Berlin, which have been tested over and over again, run about a quarter of a pound worse than a five-stage 3000-kw. and a six-stage 3000-kw. machine under exactly the same conditions in this country.

I am not a strong advocate of superheat because I believe the gain in actual fuel is small, but if superheat is to be employed, my experience shows that a great deal can be used. Some machines are endangered by superheat while others are not. The Curtis turbine is in the latter class and superheat as high as deg. may be used with safety.

W. L. Waters. The history of the steam turbine unit for power station work has been one of gradually increasing speeds, the advantages of high rotational speed being in and steam economy and reduced floor space. This has resulted in continual demand from the steam turbine builders for generators higher speed to be

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Francis
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urbines; and the degree to which this increase
:d can be seen from the fact that a standard
vhich five years ago ran at 1200 r.p.m., today

The difficulties in the design of high-speed
erators are due to the increased centrifugal
:he higher speed and to the danger of excessive
relative motion of the component parts of the
ructure. As Mr. Emmett states, it is possible
ely cheap and simple mechanical design for a
) manufacture from standard material with

With high-speed units, on the other hand,
duce greater accuracy and refinement in the
grade material and skilled workmanship in the
:o obtain the same factor of safety and operat-
an be obtained in the corresponding low-speed

:al experience that when these precautions are
are as satisfactory if not more so, from an op-
1 the corresponding low-speed ones; and a 3000-
tor carefully designed and built, or one of 10,-
is a better operating machine and has a higher
1 corresponding unit of one-half or one-third

:r is of interest because it describes one of the
rn high-speed steam turbine units and gives
dent engineers of high standing. Since the
:e so satisfactory and the unit has been so suc-
s probable that the old standard slow-speed
:ded by considerably higher speed units similar
: at the City Electric Company at San Francisco.

)N. Inasmuch as I was identified with the
; of the turbine which is the subject of Mr.
also had the pleasure of being present when the
therefore reply to some of the points brought

at the tests were not scientific in the sense that
:gated and the like, I wish, however, to em-
t that no stone was left unturned either by the
neers conducting them, in the effort to insure

I am in accord with Mr. Moultrop in deploring the fact that loads heavier than 9000 kw. could not have been carried during these tests.

Regarding the efficiencies referred to in Mr. Orrok's discussion, viz., the efficiency ratio, or Rankine Cycle efficiency, as it is variously called, and the other which Mr. Orrok prefers, viz., the B.t.u. measured in the steam at the throttle above water at the temperature corresponding to the pressure within the condenser, I agree with him that the latter is perhaps the more expressive for the user of the turbine to employ. However, it lacks particular significance, for it takes no cognizance of the power consumed by the auxiliaries. Large condensers requiring considerable power might be employed, giving a high vacuum, when a lower number of B.t.u. per kw-hr. would be shown for the turbine, which in cases might be entirely offset by the large amount of power taken to operate the condenser. It is, of course, understood that as long as the exhaust steam from the auxiliaries is condensed in a feed heater, the power taken by the auxiliaries is of little moment. However, carrying this condenser consideration to extremes, the condenser pumps might absorb as much energy as the main unit, when surely a low B.t.u. rate per kw-hr. would be of but little use to the power plant user.

For the builder and others interested in comparing the performance of one turbine with that of another, I find the efficiency ratio (the ratio of the energy actually obtained from a given amount of steam expanding between certain pressure limits and what is theoretically obtained from an ideal engine) the most convenient. This efficiency should certainly include the mechanical losses of the turbine and there is no reason why it should not also include the losses of the generator.

Comparing the turbine performance on an efficiency ratio basis, a broad view of the operating conditions must still be taken, i.e., equally good turbines may not have quite so high an efficiency ratio at a very high vacuum as for a moderate vacuum. The efficiency ratio is also varied by the amount of superheat, as already pointed out. Both Messrs. Emmet and Moultrop have called attention to the low vacuum correction on this machine as compared with the type of impulse turbines with which they are familiar. The vacuum correction for any type of machine is a variable factor, depending entirely upon the proportioning of the low-pressure blading, and the reaction type of turbine may be designed to give as high a vacuum correction as any other type. This is exemplified in Table 4, in the case of the Carville (Parsons) turbine, where an efficiency ratio of 62 per cent was obtained with the turbine carrying 29.29-in. vacuum and but 90 deg. superheat.

mercial turbines for very high vacua since in average power plant opera- cuum is exceptional. Mr. Dreyfus ion that 28 in. to 28.5 in. average near the limit which may limit somewhere, depend- ling water available ny steam used to excess of that chargeable local con-

Mr. Naphtaly's photographic repro- to calculate the terminal , I think he is taking a great es are, in fact, considerably lower cities at the low-pressure end of this er ratio to bucket velocity than has been as fact Mr. Emmet very properly points out vacuum correction. Had this turbine been ire drums of larger diameter, as it could have ing the mechanical difficulty of loosening the fears, these losses, due to the steam velocity lades, which he says amount to about 9 per of the steam, would have largely been avoided. be interesting to inquire, in view of the results iat would have been the performance of this reduction in these alleged losses. However, corrections determined from the tests them- in Mr. Naphtaly's tests to the best vacuum et Station of the Boston Edison Company, as , viz., 0.52 in. absolute mercury pressure, the ould give 12.12 lb. of steam per kw-hr., taking n of 1 per cent for each 10 deg., and 12.4 lb. superheat correction of 1 per cent for each 12 3 kw., which is less than the normal rating of

lectric turbine reduced to the condition cited Power Company's turbine at Oakland, Cal., . per kw-hr. for each superheat correction,

Attention should be called to one point, viz., e num conducted on this turbine, which when plotted, sh a general agreement. I think no tests should be regarded as entirely reliable without checking the total amounts of steam in accordance with the Willans right line law. If the tests as carried out on this turbine are correct with 11,000-kw. load, the performance would assuredly be in accordance with Fig. 4. At the time the tests were carried out, observations were made during certain swings of load up to 10,000 kw. and above, to determine the pressure drop through the admission valves, and it was found that the turbine was easily capable of carrying 11,000 kw. on the primary valve with 175-lb. gage pressure at the throttle.

CLOSURES

SAM. L. NAPHTALY. The B.t.u. per kw-hr. given in Table 1 was figured on the basis of feed water at 210 deg. fahr., arbitrarily reasoning that a credit is to be allowed in the steam plant due to the return of heat from the auxiliaries through the feed-water heater, while on the other hand, no similar operation exists in the gas plant. Inadvertently, the denoting of the B.t.u. per kw-hr. above 210 deg. fahr. was omitted in transcribing the tables. This column was included only incidentally, but for a true comparison of gas and steam plants, it is obvious that all factors in their operation must be duly considered.

In considering steam stations only, mani ly tl e heat directly chargeable to the turbine should be measured ov the condenser discharge water temperature, or more precisely, l st temperature, to avoid being affected by any inefficiency of c ndenser. Evidently, it is not always safe to adopt the last r tic d method, since the merits of different turbine installati s n be confused in a manner such that the plant producing t net overall results, including the auxiliary power, would not rank d accordingly. The turbine with unnecessarily large and p bly eful auxiliaries, or one which had had the advantage of being t ed in winter over that of another tested in summer (and correspond y influenced by a better vacuum), may very likely be unjustly cred d with a better record. One discussor gave this phase some c ion graphically.

Mr. Emmet remarked that the tests which I have ported are more favorable to the turbine I am operating than like t ts of the Curtis turbine at Oakland. An inspection of the two rent test logs, although plotted to a slightly different scale, will rev al that the con-

tical purposes, virtually the same, resulting
avor of the Westinghouse unit.
arison which Mr. Pigott discusses, authori-
eciably as to the value of superheat in the
believe some engine experts assert 6 per cent
mprovement in the economy of the engine
ed to 100 deg. fahr., which is much less than
Moreover, it does not appear consistent to
a combined unit performance for superheat,
ary the City Electric turbine economy to the
ig the Interborough plant tests. Had all
the same direction, i.e., for the City Electric
heat, as seems most logical in this discussion,
practically with the smaller difference noted.
note that this turbine has since been operat-
same degree of efficiency as on the tests.
the actual water rate, we have kept a very
nsumption of the plant during the hours this
om that we draw the conclusion as suggested

to clear up a question which arose in the dis-
apacity of the turbine, I would say that the
ring the winter to put out upwards of 12,000
recorded was practically in accordance with
gage pressure and at 11,100 kw., the drop
valve was as plotted. The auxiliary valve
ls above 11,100 kw.

ying to Mr. Moultrop, the total cost of the
ows:

	Per Cent of Total Cost
..... $51	
.....	13.45
.....	32.09
pipe and boiler room auxiliaries....	35.50
auxiliaries.....	6.45
.....	8.27
.....	3.04
.....	1.20
	100.00

, I would say that our specifications called for
the dry vacuum pump barely came within

the guarantee. We are about to install a pump of larger capacity, inasmuch as all other conditions are adequate for a better vacuum.

The matter of more superheat is a more difficult proposition and on account of the doubtful total gain in efficiency, we are inclined to let that remain as it now is.

In reply to Mr. Emmet, I would say that when the turbine was erected some foreign material was accidentally left on two of the bucket wheels, damaging the buckets of the third and fifth stages, and that the manufacturers estimated before the test was run that new buckets in the place of the damaged ones would increase the water rate 1 lb. per kw. The results of the test, however, were given as they were made, without regard to what should have been the water rate of the turbine.

No. 1300

CONDITIONS OF PASSENGER ELEVATORS

REGINALD P. BOLTON, NEW YORK
Member of the Society

erned with the principles affecting and limiting
ger elevators. These constitute the most impor-
mprovement of real estate and are continually
ed in this connection.

of a passenger elevator is unlike that of other re-
sms, in that its movements are designedly de-
ntrance and exit and the weight of the persons
. The time during which it is in actual motion
t of the total time of its service, and it will be
ue proportion of the total time may be expected
ssenger movement and by machine motion re-
d either one or the other be of undue proportion,
duction in efficiency, as represented by traffic.
is that which is consumed while the car is not
iting the movement of passengers. In schedule
method of operation universally adopted in bus-
period of actual waiting time at the lower floor
dule, but in addition to this time, the movement
ering and leaving the car and the processes of
the gates occupy a further proportion of the
he elevator.

naction of an elevator thus has a close relation
sengers carried, and in schedule service the aver-
ime which the writer advanced in a recent work
een found by experiment to prevail in various
t personal characteristics in the use of elevators
l parts of the country. These allowances are:

al Meeting, New York 1910, of THE AMERICAN SOCIETY
ERS.

a For each person carried either way ..... 5 sec.
b For each person entering at the lower landing..... $1\frac{1}{4}$ sec.
c For each person leaving at lower landing..... $\frac{3}{4}$ sec.
d For the process of making and leaving the upper landing..... 9 sec.

The waiting time at the ground floor, in addition to the foregoing is extended to suit the schedule, which is fixed by the division of the round-trip time between the number of elevators in use. In several tests of the traffic of schedule service, by making the foregoing deductions from the total time occupied, the actual running speed of the elevator car has been correctly predetermined and in others, by deducting the known running time from the total, the foregoing allowances have been substantiated.

5 The machine time is occupied by three main elements:
a Acceleration from a state of rest to designed speed.
b Travel at designed speed.
c Retardation from designed speed to a state of rest.

The average speed of the machine is not its designed or nominal

TABLE 1 MEAN SPEED AT VARIOUS FUNCTIONAL DISTANCES

Flight	Functional Distance	
	10 Ft.	15 Ft.
Ft.	Ft. Per Sec.	Ft. Per Sec.
12	4.60	3.73
15	5.00	4.16
18	5.35	4.52
24	5.90	5.13
30	6.33	5 55

speed, but that which results from the mean time occupied in the foregoing operations. The designed speed may not be attained unless the flight or distance between stops is such that the processes of acceleration and retardation from and to a state of rest do not occupy the entire space of time and distance.

6 Fig. 1 shows the course of these functions on a horizontal scale of time and a vertical scale of space, with the mean speeds resulting therefrom. Line *AB* is that of the designed speed of the car at 500 ft. per min. Curve *CD* is that of the function of starting and stopping on the up-run within distances respectively of 6 and 4 ft. and *C'D'* the same operation on the down-run and within a flight from landing to landing of 15 ft. The mean speed is reduced to 5 ft. per

FIG. 1 SPEEDS AT VARIOUS FUNCTIONAL DISTANCES

sec., a drop of 40 per cent from the designed speed. Curves EF and $E'F'$ are those of the same functions exercised in a distance of 10 ft. and 5 ft. respectively, thus occupying the entire space from landing to landing and reducing the mean speed to 4.16 ft. per sec., or 50 per cent of the designed speed. From these and similar curves the mean speeds given in Table 1 have been deduced. In curve EF it will be seen that the car on attaining its designed speed, is immediately slackened by the commencement of the process of

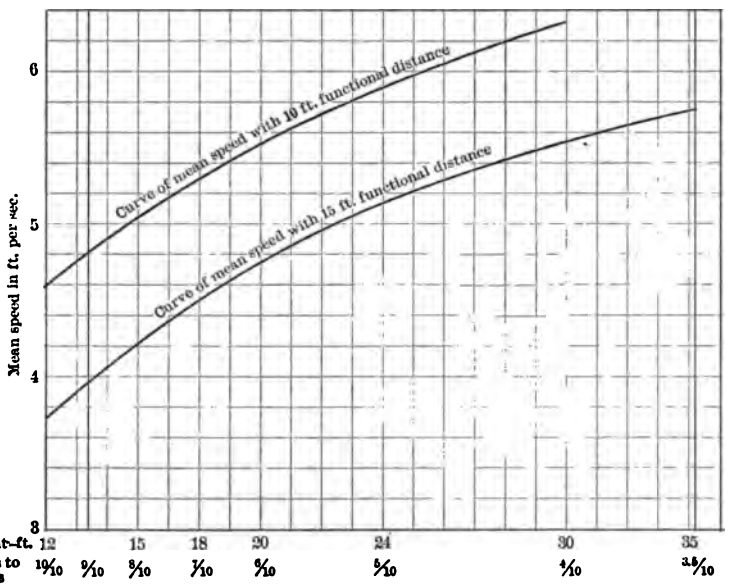


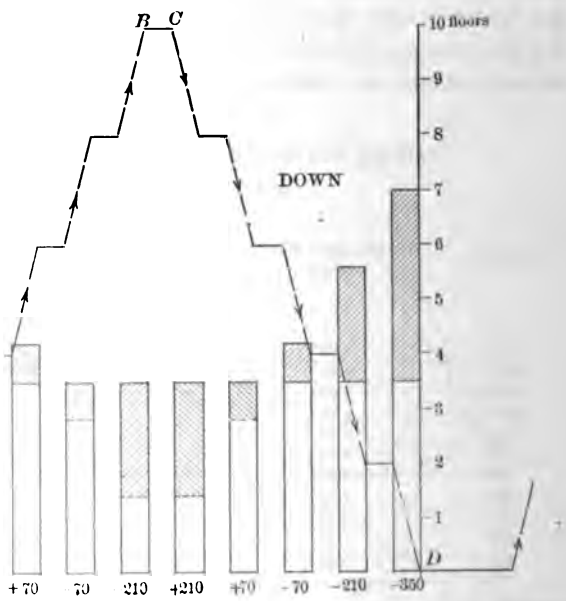
FIG. 2 MEAN SPEEDS BETWEEN LANDINGS AND CORRESPONDING SERVICE

retardation so that the designed speed is not utilized at any less distance than 15 ft. between landings.

7 Fig. 2 shows these rates of speed at the same two functional distances plotted for all distances between landings from 12 ft. to 35 ft., with the corresponding character of the service expressed in percentage of landings to floors.

8 The gain by the shorter functional distance when making any service is about 12 per cent of machine time, and such an elevator will, if sufficiently powerful for the increased load, attain the same mean speed with $\frac{6}{10}$ traffic as is attained in the other machine with four landings in ten floors.

e car and the weight of the car itself directly
celeration and retardation, aiding or opposing
on the up and down runs. Where there is
lance applied to the live load, these effects
ed to the latter. In hydraulic elevators it
le to counterbalance the live load, but it is
o counterbalance some part of the live load



3 EFFECT OF COUNTERBALANCE

relieving to that extent the two operations in
electrically operated elevators are now largely
re constantly on the increase, the relation of the
e average live load carried each way appears
it feature and it would be desirable to ascertain
anner rather than by theoretical assumption.
are varied on the up and down runs in the man-
n which the flights and stops of a car are shown
ne weights by the shaded parallelograms. The
ne-half of the commencing and ending live loads,
ffect of bringing about a complete balance of

lifting and lowering work, and theoretically the net o
lifted on one side is used as descending force on the oth
due to this feature that the electrical form of elevator will
a certain amount of motor-generated current to its supply
amount so returned is but a portion of that used in lifting
balance and is usefully employed only if there be some means
ing or utilizing the current. The motor must also be back-
that speed necessary to produce a voltage equal to that
cuit which is only the case when it has attained its designed
that this economic feature is also dependent on the average
between stops and starts.

TABLE 2 TESTS AT NIGHT AND DAY BANK BUILDING

AVERAGE LOADS—CAR NO. 2

Hour	Persons Each Way, Average	Live Load, Lb. 100-200	200-300	300-400
7- 8	0.75	105	—	—
8- 9	2.09	—	292	—
9-10	2.62	—	—	366
10-11	2.33	—	—	326
11-N	1.91	—	267	—
N-1	2.55	—	—	338
1-2	2.67	—	—	349
2-3	2.65	—	—	347
3-4	1.29	181	—	—
4-5	1.73	—	242	—
5-6	1.67	—	233	—
6-7	0.94	131	—	—
Averages		139	259	345

11 The effect of overbalance is also varied by the fluctuations of the live load in either direction during the urs of traffic, and should this traffic be uneven or such as to vary co iderably from the designed relation of load to overbalance, then the nefit of the over-balance is disturbed and its value is considerably impaired.

12 The relation of traffic to counterbalance is herefore a matter of importance, and economy may be effected by rtaining what proportion the average loads each way bear to overbalance. These relations may be ascertained after the appl ce is in full operation by counting the passengers, but this observati not of value unless the counting is made of every individual l each way during some given period of time.

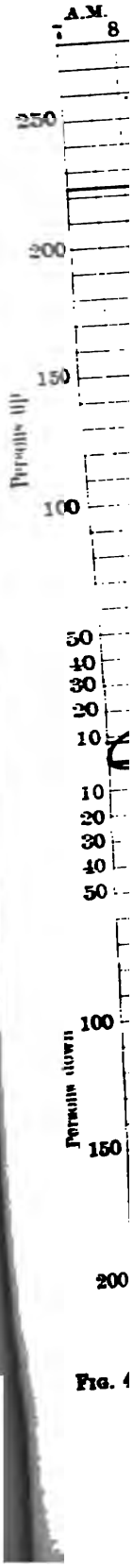
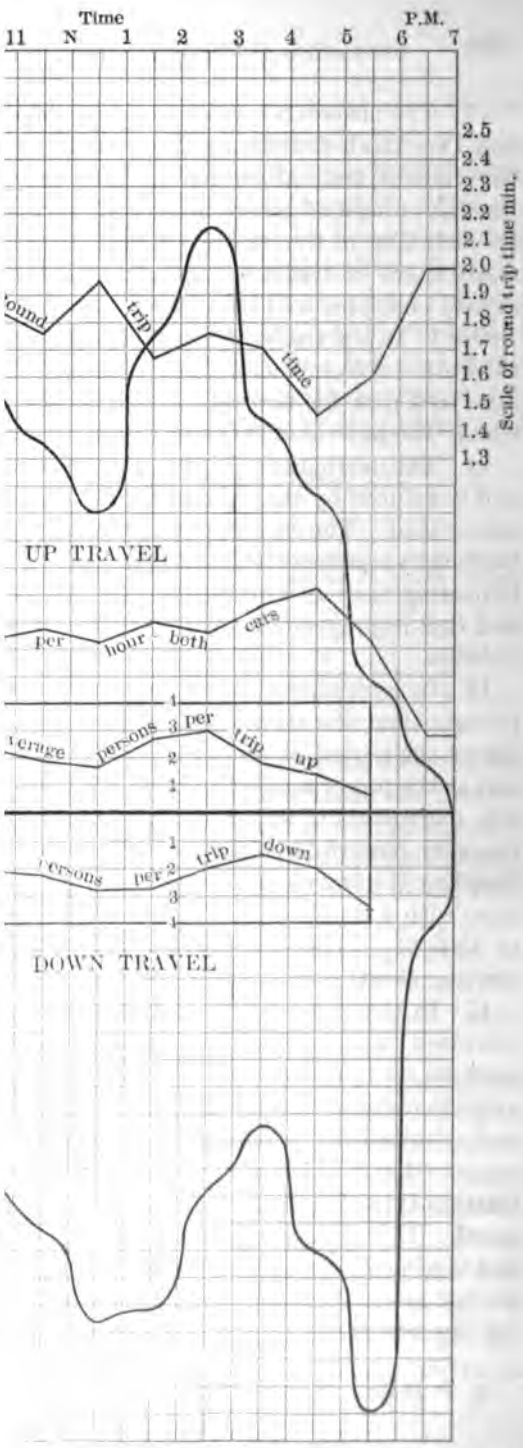


FIG. 4



IN NIGHT AND DAY BANK BUILDING, NEW YORK CITY

13 The observed operation of the traffic in the cars of the Night and Day Bank Building is shown in Fig. 4, in which are plotted on the vertical scale above and below the middle horizontal line the number of persons carried up and the number of persons carried down on each hour of the business day. This observation shows that the distribution of traffic in such a business and professional building closely coincides with the theoretical distribution advanced by the writer.[1] In the traffic of this building, the heaviest periods of elevator work are from 9 a.m. to 10 a.m. for one-way traffic, and from 2 p.m. to 3 p.m. for two-way traffic, periods which may differ in other cities. The individual work of one car is given in Table 2.

14 The overbalance of these machines is about 800 lb. of live load and is reduced by the weight of the operator to 660 lb. of actual passenger load. The excess or overbalance of the actual mean passenger loads thus becomes 520 lb. for 3 hr., 400 lb. for 4 hr., 310 lb. for 5 hr., indicating that an unnecessary amount of overbalance is provided and that improvement could be effected by reduction of the counterbalance.

15 In hydraulic-cylinder elevators, and notably in those of the plunger type, the absence of counterbalance of the live load not only varies the period of acceleration and retardation to a wide extent, but as the power applied to these machines is fixed in extent, successive increments of load also vary the traveling speed. On a test of the very powerful hydraulic-cylinder elevators of the Hanover Bank Building, the traveling speed both up and down varied from 880 ft. per min. with a live load of 550 lb. to 330 ft. per min. with a live load of 3300 lb. The characteristics of the functions of stopping and starting varied as shown in Table 3.

16 In the plunger type of machine, the effects just described are increased on account of the large mass of material and water which must be set in motion to and arrested from the same speed as the car and the result is that both the period and the distance of acceleration and retardation are relatively prolonged. These effects are largely negatived in the electrical elevator, even where, as in the case of the traction type, the ropes and the counterweight all travel at the car-speed. This result is obtained by the introduction of the electrical and mechanical brake action in retardation, and by the ability of the electric motor to exert force in acceleration and motion approximating the resistance of its load. These capabilities have been very

[1] R. P. Bolton, Elevator Service.

one-to-one traction electrical elevator, in
ortions accompany its relatively slow speed
dislodging the cables from the head sheaves
ne up-run or of putting excessive strain on
tardation are overcome by the arrangement
s form of machine therefore offers the larg-
tions discussed, affording maximum powers
l speed with all loads, and safe retardation.
se powers, it will remain a fact that if the
such as to demand a stoppage within a dis-
pied by the operations of acceleration and

'S AT HANOVER BANK BUILDING
NCTIONAL DISTANCES AND SPEEDS

eleration Up, etardation Down, Ft.	Retardation Up, Acceleration Down, Ft.	Functional Distance, Ft.	Mean Speed in 24 Ft. Per Sec.
11	6.6	17.6	2
7.25	7.75	15	7.15
6.1	12.3	18.4	8.1
5	24	29	6

en described as the functional distance, the
attained. Therefore, unless the number
the traffic as to afford an average distance
the functional distance, there is no advan-
signed speed. As high rates of designed
e forces, which in each type require either
pply or large proportions of apparatus, it
l economy in first cost may be secured by
tors to their work that the best results
most moderate designed speed.
ticularly in those electrically operated, the
oportion to the number of starts and stops.
the use of the electric motor, in which the
is required for the process of first motion
largest for electrical and mechanical re-
ount for the actual running speed, with a
to the continuous excitation of the field.
n this form of elevator, which is now so
t of the consumption of power is directly
ps and starts which accompany and result

from the number of persons carried. The diversities in results which have been reported from time to time as to the consumption of current by electrical elevators may be attributed to variations in traffic conditions.

19 A series of very interesting tests was recently made upon the operation of a one-to-one traction elevator in the ten-story building of the Boston Edison Company, in which observations of the use of current were made at varying numbers of stops and starts with various loads.

TABLE 4 CURRENT CONSUMED BY AN ELECTRIC ELEVATOR AT VARIOUS LOADS AND STOPS

Stops	Up	1st and 9th Floors					1-5-9				
	Down	9-1					9-5-1				
Distance		101 ft. 6 in. one way or per trip=52 trips per car-mile									
Load lb		Oper.	666	1060	1360	2010	2360	2660	Oper.	666	1060	2010	2660
Kw-hr. per Car-Mile		2.345	2.075	1.945	1.87	2.15	2.495	3.22	3.09	2.855	2.52	2.915	3.859

Stops	Up	1-3-5-7-9				1-2, 3, 4, 5, 6, 7, 8, 9			
	Down	9-7-5-3-1				9-8, 7-6, 5, 4, 3, 2, 1			
Distance		101 ft. 6 in. one way or per trip=52 trips per car-mile							
Load lb		Oper.	666	1060	2010	Oper.	666	1060	2010
Kw-hr. per Car-Mile		4.91	4.185	3.975	4.25	7.285	6.75	6.7	7.425

Machine: Otis Elevator Company's One-to-one Electric Traction.
Total Weight of Car: 3956 lb.: Overbalance = 1060 lb.
Capacity: 2500 lb. at a speed of 500 ft. per min.
Tested: Boston, Mass., June 1907.

20 The writer has plotted from these results a series of curves shown in Fig. 5 which indicates very clearly that at all loads an increase in the number of stops results in a progressive increase in the current consumption. The shape of all these curves is affected by the relation of the overbalance to the load and at or near the balance point the most efficient service is naturally attained.

21 In hydraulic elevators the cost in energy of stops and starts is that of the water under pressure, which is used for the reversal of

FIG. 5 CURRENT CONSUMPTION OF ELECTRIC ELEVATORS AT VARIOUS LOADS AND STOPS

the valves. In a test of the plunger elevators in the Un... Express Building, in which the writer took part, the proportion ... water thus used in stops and starts was ascertained to be, on the ba...

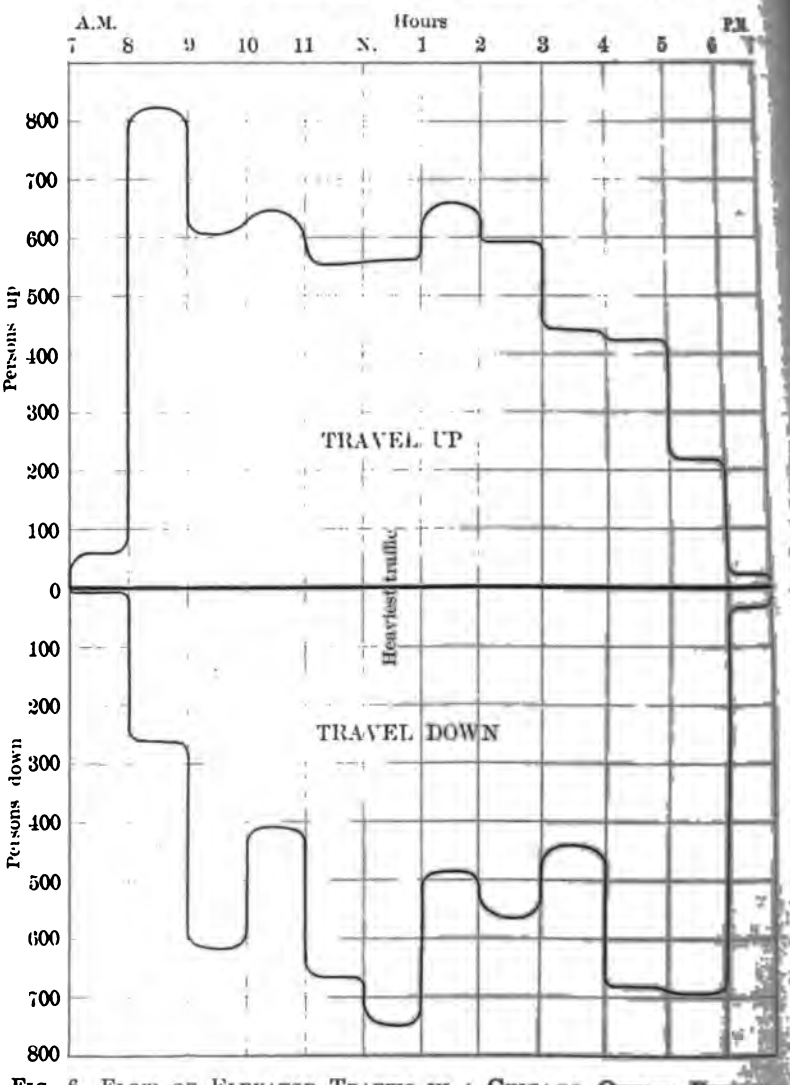


FIG. 6 FLOW OF ELEVATOR TRAFFIC IN A CHICAGO OFFICE BUILDING

of four stops up and four stops down to ten floors ...bove the ground, 11.1 per cent of plunger displacement, and on ... ...asis of a stop at every floor up and down, 22.2 per cent.

FOLDER No. 11

FOLDER No. 12

each way in the average round-trip time of 3.07 min. The average round-trip time of the schedule as maintained was 3.09 min., and the best time for an individual car was that of car No. 2 which made certain trips in 2.5 min. round-trip time, carrying 4.35 persons each way, at the rate of 104 persons per hour.

26 It will be observed that at various times the operation of car No. 3 and car No. 6 was interrupted by their diversion from the service for freight purposes, and at the particularly busy time near one o'clock, when this occurrence took place on car No. 3, the traffic was forced into the other cars, the loads on which were greatly increased, with the result that the number of round-trips made by those cars was reduced.

27 The division of passenger time and machine time in these cars was ascertained by observations of the speed of two of the cars with a live load of three passengers each way. On a run from top to bottom of the shaft, the speed developed under those conditions, was 6.77 ft. per sec., corresponding to a designed speed of 400 ft. per min. With the same load, but starting and stopping at every alternate floor, the mean speed fell to 4.8 ft. per sec. As the schedule maintained by the service allowed an interval between arrival and departure of cars at the ground floor of 30.9 sec., the actual time of the average trip became 154.5 sec. The average speed of 4.8 ft. occupies 80 sec., leaving for passenger time, less the top landing, 65.5 sec. The average number of persons carried by two of the cars when operating at this speed was 6.6 each way, or 13.2 in all, so that the passenger time was 5 sec. per passenger per landing, which is the allowance to which reference was previously made.

28 These observations indicated further that the elevators were capable of handling the busy-hour traffic at the rate of four landings to ten floors and were operated under an average of three and one-tenth stops to ten floors, affording an ample service readily capable of meeting the variations in the flow of traffic. They also indicated that during the heaviest period of the day when the relation was increased by the withdrawal of one car, the time of the round trip was delayed and the schedule lengthened, reducing the convenience and the efficiency of the service.

DISCUSSION

E. HOLLANDER. In Par. 18 the author states that in all elevators, particularly those electrically operated, the use of power increases

FOLDER No. 12

loyed by the author in securing data bearing
observation of the number of persons carried
/ each elevator in a given time. Such observ-
in a number of buildings of widely differing
ers, in cities as far apart as Seattle an Atlanta,
cteristics as Detroit and Portland, Ore. In
e proved of value by indicating opportunities
vice and in economy and have also confirmed
ıs as to the influence of traffic upon speed and

ınd comprehensive example of this method of
:ded by the six hydraulic elevators of a Chicago
ories located in the heart of the business dis-
ofessional, business and brokerage tenantry.
servations are plotted in diagrammatic form in
: upward and downward traffic is plotted ver-
ɔw the middle horizontal line and the period
the horizontal scale. In Fig. 6 the total com-
.ch way is shown and from it is observable the
uring the hours of business, the heaviest period
fic from 8 to 9 a.m. and for two-way traffic from
total combined traffic for the day's service was
up and 5801 carried down.
ɔmbined schedule work of the six cars is plotted,
/f persons lifted or lowered by all six cars on each
affording a picture of the response of schedule
of traffic. The average total of the six cars per
double dotted line on the upper and lower part
average number of persons per hour per car is
single dotted line. The average number of per-
er hour was 5 up, 4.91 down, and 4.95 each way.
ɔer hour aggregated 584 persons.
he work of these cars in still greater detail, the
he individual work of each car per trip, affording
f the division of the work between the several
sting observations can be made from this dia-
rk of the day was found to have been done by
ing the busy hour of noon to 1 p.m. carried 264
of 6.6 each way per trip. The heaviest day's
r No. 5, which carried an average of 5.34 persons

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; and stops.

that for hydraulic elevators the energy used
iat of the water under pressure used for the
This is true only of machines provided with
valves operated by pressure water.

re to present a closure.—EDITOR.

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'IELD FOR GRINDING

[. NORTON, WORCESTER, MASS.
Non-Member[1]

forms has been known to man from the very yet it is doubtful if many engineers have a he field for metal grinding. My experience enty-five years has taught me that the usual as a slow, tedious, expensive but sure method and that where great accuracy is not required e done.

abrasion as "the act of wearing or rubbing by friction, as the abrasion of coins," abrade, ıy by friction, as to abrade rocks." He defines rubbed smooth, as an abraised table," mean- No doubt here is the connection between ›n.

n the last 75 to 100 years men discovered that wheel enabled them to abrade work in such a ime that so far as polishing was concerned it : tedious. But as the original word for abrasive ınd grinding was slow, men still clung to the ıe later discovery that polishing could be done ıin the recollection of the writer, mechanics glue and emery wheels with which to grind ork, it did not occur to them that they could ıin part of the work that they were using steel

ıl Meeting, New York 1910, of THE AMERICAN SOCI-
ıINEERS.

16 While it is still true that poor wheels or good wheels poorly selected and wrongly used will remove metal very slowly by abrasion, it is also true that the old-fashioned milling cutter, with fine teeth cut by hand with a file, hardened but never ground, and used in the old-time slender milling machine, would very slowly abrade the surface. The modern grinding wheel, used in a modern machine by a modern man, is just as surely a milling cutter as if it were made of steel.

17 The microscope reveals the fact that such a wheel cuts off chips. Fig. 1 is from a microphotograph and clearly shows the chips that are as surely cut off as those made with a steel milling cutter. The grinding wheel used was a modern one made of crystalline aluminum oxide.

FIG. 3 FIG. 4

FIRST TWO STAGES IN THE GRINDING OF AN AUTOMOBILE CAM

18 Fig. 2 is also from a microphotograph and shows the result of the old-fashioned abrasion described by Webster as grinding to powder. Here we see the effect of great heat, the greater part of the powder being in the form of globules. This is magnified to the same extent as the other photograph and shows the vast difference between the old-time abrasion to powder and the present cutting chips. A large part of the energy put into work was wasted in heat, as shown by the very small globules in Fig. 2. The wheel used for Fig. 2 was an emery wheel like those referred to in Appleton's Cyclopædia of 1893.

19 The grinding wheel as now made is really a milling cutter with millions of cutting teeth. Although these teeth are not as large

f a steel cutter and therefore cannot cut as
le of cutting at much greater speed. Since
them they are capable of much more work
nature of the work is such that a large
oints can be used simultaneously. In some
y as two billion cutting points per minute.
minute is not uncommon and four hundred
r common.
ng wheel, mounted in a good machine, can
d of 6000 or more surface feet per minute
peed it need not cut deeply relative to the
erefore it is able to remove metal from many
ly than the milling cutter or the lathe tool.

g. 5 FIG. 6

N THE GRINDING OF AN AUTOMOBILE CAM

; illustrations show a notable example. Figs.
cess of making automobile cams. An order
as was received and our shop superintendent
for producing them at the lowest possible
drop forgings for so few would be out of the
of dies would make the cost of the cams pro-
e necessary to devise means for producing
This was done by providing an eccentric
screw machine. To prevent the bar from
le feeding forward, the spline was made the

full length and a mating key was placed in the chuck. Fig. 3 were made in the automatic machine at the rate of 10 per hour. A keyway in the hole was made in the ordinary way, Fig. These blanks were ground to rough shape, Fig. 5, at the rate of 10 per hour. The cams were then hardened and finis d ground to Fig. 6 at the rate of 40 per hour. It should be clear that such a cam could not be milled to shape from the blank in nearly so short a time with the milling cutter. When manufacturing such cams in large numbers drop forgings would be used, and here again the grinding wheel is quicker than the milling cutter.

22 Another case where the grinding machine can accomplish the results desired in less time than the lathe is that of the pins and bearings of the automobile crankshaft. The results desired are as follow

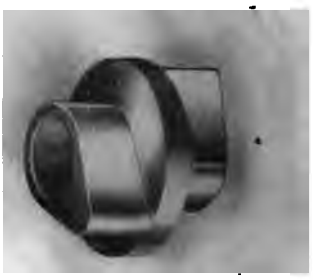


FIG. 7 DOUBLE CAM GROUND FROM ROUGH STOCK 2 IN. IN DIAMETER

Five bearings, all round within 0.00025 in.; e axis of all parallel and exactly in line; all of the right length n 0.004 in.; distance between bearings within 0.004 in.; accumulated error not over 0.008 in. Four crank pins, all round within 0.00025 in.; the axis of all exactly parallel; all to length within 0.004 in.; all parallel with the bearings; all within 0.005 in. of the same lane; all of correct throw, within 0.010 in.; overall length, accu ulated error not over 0.008 in.; all fillets correct radius and exactly concentric with the bearings and pins; all bearings and pins straight within 0.00025 in. and all a good, smooth surface.

23 In the case of cranks designed with ance for the arms of the cranks, as shown in Fig. 8, the width of t heel is identical with

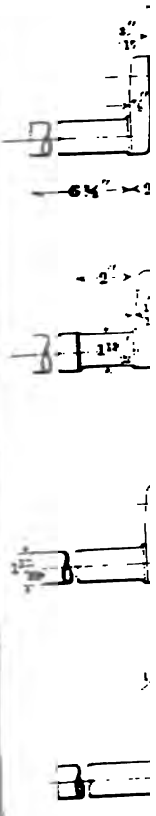
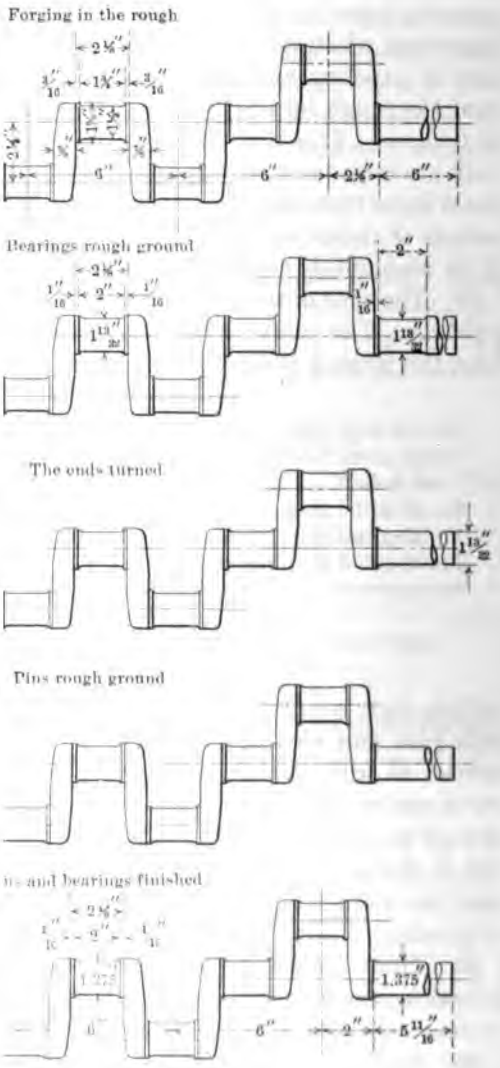


FIG.

the requ
or settin
grinding



GRINDING OF AN AUTOMOBILE CRANKSHAFT

pins and bearings, so that no measuring
ecessary for cutting to length. The act of
r pin the right length and forms the fillets.

The location of the pins and bearings within the small limits allowed is accomplished by a massive index bar, so that the workman does no measuring whatever for location of bearings or pins. The entire time of handling and producing these five bearings and four pins from the rough forging to the nicely-sized and finished condition is 85 minutes. It is clear that when all the conditions of the finished work are considered, the grinding wheel and machine have removed metal faster than the lathe. Again, it is not simply a case of removing pounds of metal per hour, but the removal of it in such a manner as to accomplish certain results in the least time.

24 The ends of these shafts beyond the bearings are turned before grinding. The entire list of operations to make a finished shaft from the forging is as follows: .

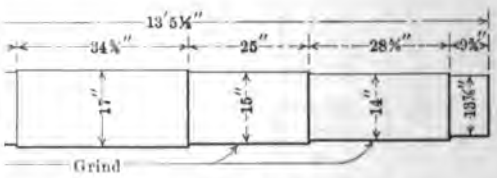
Cut off ends and center	6 minutes
Rough grind bearings	15 minutes
Turn ends	8 minutes
Rough grind pins	20 minutes
Finish grind pins	20 minutes
Finish grind bearings and ends	25 minutes
Square ends	6 minutes
Total time	100 minutes

A little time could be saved if it were practical to secure forgings with pins and bearings $1\frac{5}{8}$ in. in diameter over their entire length instead of with the depression to $1\frac{1}{2}$ in. between shoulders, as the wheel can be forced more rapidly when the face has the same amount of work to do as the fillets. Here again tradition is strong and difficult to change at once, because the depression is better for those who turn the work. A little coöperation would save on dies and time in grinding.

25 There are hundreds of other cases where the grinding wheel is used to remove metal in a more economical manner than with steel-cutting tools, some of which are shown in Figs. 9 to 20.

26 Automatic grinding is a late development in the field. Certain work of which large numbers of pieces are made is ground by wholly automatic means. The work is conveyed to the machine by gravity in a hopper or chute and is chucked, ground and delivered to the receptacle. In a case where formerly, at piece work, 300 per day were ground, the automatic machine grinds 4 in a single minute, about 2300 per day.

ge of grinding becomes more common and
d production on the part of the workmen
rly overcome, the field will be still more
of more systematic coöperation and if we
ewarded with success. The engineer is the
training is best fitted to take up the impor-
for grinding.

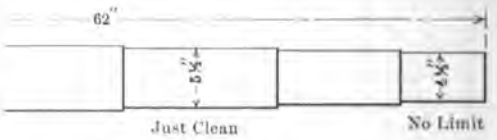


INE SHAFT—HAMMERED FORGING

ved, 0.025 in.; limit, 0.001 in.; time, 6 hr. (8 hr.
ncluding handling)

SHAFT 0.30 CARBON STEEL

t, as noted; time, 1 hr. (including setting up)



PINDLE—CRUCIBLE STEEL, HARDENED

.; limits, as noted; time, 1½ pieces per hr.

PIN—0.15 CARBON STEEL, HARDENED

.; limit, 0.0005 in.; time, 60 pieces per hr.

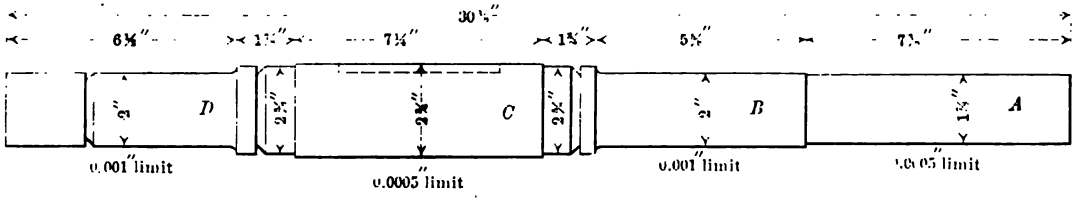


FIG. 13 ARMATURE SHAFT—0.30 CARBON STEEL

Stock removed, $\frac{3}{64}$ in.; limits, as noted; time, 3 pieces per hr.

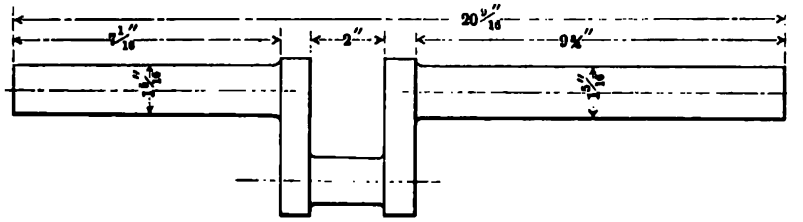
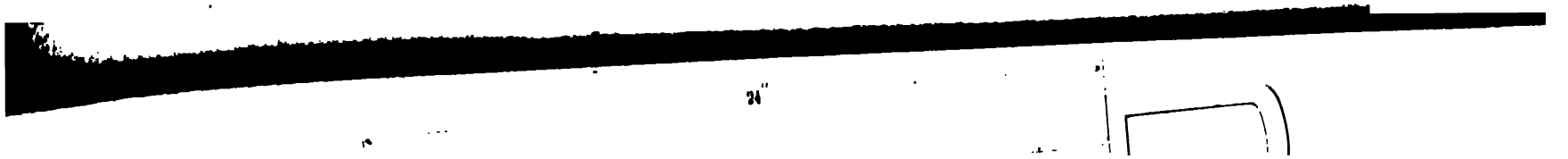


FIG. 14 CRANKSHAFT—0.45 CARBON STEEL

Grind bearings only; stock removed, 0.015 in.; limit, 0.0005 in.; time, 50 pieces in 7 hr. 15 min.



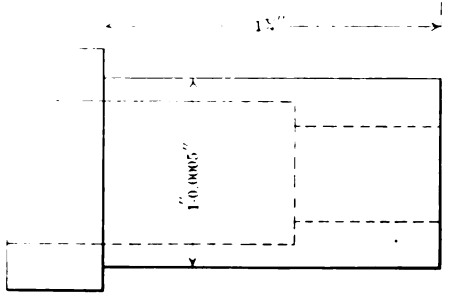


FIG. 16 BUSHING—CAST IRON

Stock removed, 0.010 in.; limit as noted; time, 45 pieces per hr.

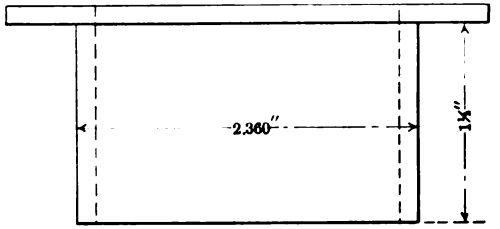


FIG. 17 BUSHING—PRESSED STEEL

Stock removed, 0.025 in.; limit 0.0005 in.; time 60 pieces per hr.

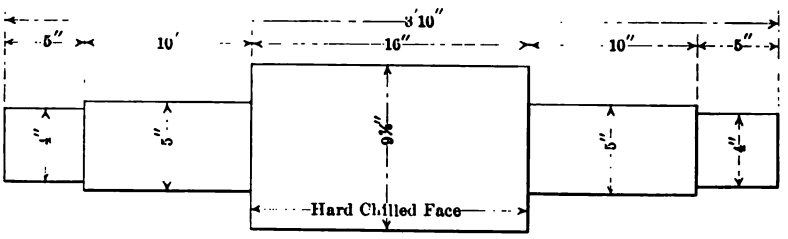


FIG. 18 CHILLED ROLL—CHILLED IRON

Stock removed, $\frac{3}{8}$ in.; time roll face, $2\frac{1}{2}$ hr.; previous lathe time, 12 hr.

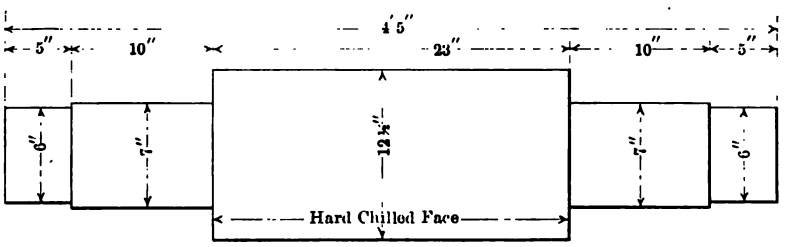


FIG. 19 CHILLED ROLL—CHILLED IRON

Stock removed, $\frac{1}{2}$ in.; time roll face, 7 hr.; journals and ends, $3\frac{1}{2}$ hr.; total, $10\frac{1}{2}$ hr.; lathe time for same work, 23 hr.

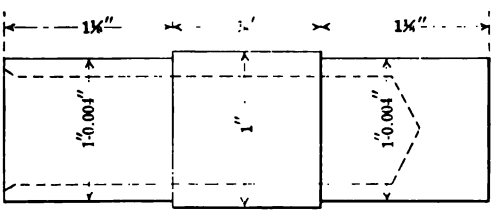


FIG. 20 PISTON PIN—MACHINE STEEL, HARDENED

Stock removed, 0.015 in.; limit, 0.0005 in.; time, 25 pieces per hr.

No. 1301*b*

ECISION GRINDING

W. A. VIALL, PROVIDENCE, R. I.
Member of the Society

ı art rather than an exact mechanical operation.
ecent growth that relatively little is known about
. In the development of the grinding machine
nning, as described in the historical article in
910, to the present well-known makes of univer-
ıg machines, the successive steps that have been
ng stability and convenience in the machine form
of mechanical history, since they show, as well
hines, the tendency of the times.
of grinding as an art, I mean that it contains ele-
judgment and experience of the operator count for
in a general way the manufacturer or the skilled
ive instructions for the running of the machines,
vhich make it necessary to vary from these instruc-
tain the best results. To instruct an operator
l and speed would make it possible for him to
the three results. When ground with a wheel
true a piece looks as though it had been gouged
while with a wheel surface that is true it gives a
ws the wheel marks. The latter is what we
l grinding. When this same wheel has been
nts of the abrasive become somewhat dull, we
hed surface. All these results are possible with
ler different conditions.
e interested in two classes of grinding. One is the
such as we find in the tool room and in the shop

nual Meeting, New York 1910, of THE AMERICAN SOCI-
ENGINEERS.

where one or two pieces of a kind are made and where accurate fits are demanded. The second is the manufacturer's problem where not only must the nicest accuracy be obtained but where the rate of production is an important consideration. In the first case the question of cost does not enter so deeply into the problem, although it is always to be considered; and one machine, specially designed to do a certain class of work, is often compelled to answer the necessities for work to which it is not well suited. In the second case, however, the best results as to efficiency and production are obtained by having a machine of the proper size. It must be understood from the first that whether the machine is large or small it must be sufficiently heavy and stable enough to do the work it is called upon to do and it must be so designed that it can readily be operated. This latter element of convenience must be provided for even more carefully than in many other classes of tools, because much of the work done in the grinding machine is of such a character that the operations of putting in and taking out consume almost as much time as the grinding. Moreover, a grinding machine must have sufficient rigidity to preserve its alignment, which must be of a high grade from the first. Unless the machine is capable of producing true work its value is lost, for the grinding machine must not only finish work but also rectify it to a degree of accuracy that we cannot in reason look to a lathe or other type of machine to furnish commercially.

31 The principles of grinding, in the main, are not difficult to grasp, and the time that would be required of the ordinary chief operator in grasping them is not excessive. But the work does require such attention and knowledge of the results that can be obtained, coupled with the skill acquired by experience, as to class it with the Arts. In the early days it seemed quite necessary that for every different piece of work we should have a different wheel. Later it was found that a given wheel would give satisfactory results on various kinds of work by varying the speed of the wheel, the speed at which the work was run, or the feed of the work, so that one wheel answered a great variety of purposes. There have been changes in abrasives and we are getting today a far better quality of wheel than was possible some years ago. The grading of wheels has very much improved, and although in the writer's opinion it is not possible to obtain an absolute grading, this element has been reduced to such a nicety that it need not be taken largely into account by the average operator.

32 The first use of the grinding machine as we know it today

rrors that were impossible of eradication by emery cloth. Today the grinding machine and in addition finishes work for appearance cheap manner.

machine has been selected, the choice of wheels ed knowledge which the makers of machines sition to furnish to an extent that many of the s are probably not aware of. When the proper e once established for a given line of work their y easy.

f speeds and feeds is also the result of experience, the manufacturers will help users to a great satisfactory results. The cutting operation of own in an illustrated article by Messrs. Gribben the microscopic photographs showed that the nbled those made by a lathe tool. It is only ns, however, that these results can be obtained. rue and they must not be forced into the work t, for this produces a torn effect upon the work, ed.

a piece of work to be done, first of all the ques- size and the limits suitable for the purpose for Table 1 gives the limits used at the Brown & orks for varying conditions. There are special necessary to increase or to decrease these limits, offered as the final word but as a guide towards

essity is that sizes should be established to which ough turned ready for the grinding room. In tories, the aim is to produce the desired results e. Our desired ends have been accuracy and the parts ground are for fits, and nicety of finish d. To do this work as cheaply as possible we nomical to turn the pieces to about the sizes It will be noted that we allow from 0.008 in. er, an amount easily obtained by the ordinary n order to make this work as easy as possible for we furnish the limit gage shown in the sketch. tice varies on this point, and we have thoroughly

TABLE 1 GRINDING LIMITS FOR CYLINDRICAL PIECES*

AS ADOPTED BY BROWN AND SHARPE MFG. CO.

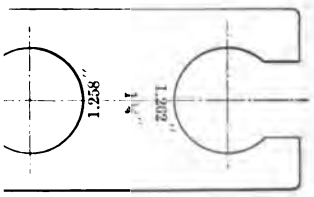
RUNNING FITS—ORDINARY SPEED			
To ½-in. diameter, inc.	0.00025	to 0.00075	Small
To 1 -in. diameter, inc.	0.00075	to 0.0015	Small
To 2 -in. diameter, inc.	0.0015	to 0.0025	Small
To 3½-in. diameter, inc.	0.0025	to 0.0035	Small
To 6 -in. diameter, inc.	0.0035	to 0.005	Small
RUNNING FITS—HIGH SPEED, HEAVY PRESSURE AND ROCKER SHAFTS			
To ½-in. diameter, inc.	0.0005	to 0.001	Small
To 1 -in. diameter, inc.	0.001	to 0.002	Small
To 2 -in. diameter, inc.	0.002	to 0.003	Small
To 3½-in. diameter, inc.	0.003	to 0.0045	Small
To 6 -in. diameter, inc.	0.0045	to 0.0065	Small
SLIDING FITS			
To ½-in. diameter, inc.	0.00025	to 0.0005	Small
To 1 -in. diameter, inc.	0.0005	to 0.001	Small
To 2 -in. diameter, inc.	0.001	to 0.002	Small
To 3½-in. diameter, inc.	0.002	to 0.0035	Small
To 6 -in. diameter, inc.	0.003	to 0.005	Small
STANDARD FITS			
To ½-in. diameter, inc.	Standard	to 0.00025	Small
To 1 -in. diameter, inc.	Standard	to 0.0005	Small
To 2 -in. diameter, inc.	Standard	to 0.001	Small
To 3½-in. diameter, inc.	Standard	to 0.0015	Small
To 6 -in. diameter, inc.	Standard	to 0.002	Small
DRIVING FITS—FOR SUCH PIECES AS ARE REQUIRED TO BE READILY TAKEN APART			
To ½-in. diameter, inc.	Standard	to 0.00025	Large
To 1 -in. diameter, inc.	0.00025	to 0.0005	Large
To 2 -in. diameter, inc.	0.0005	to 0.00075	Large
To 3½-in. diameter, inc.	0.00075	to 0.001	Large
To 6 -in. diameter, inc.	0.001	to 0.0015	Large
DRIVING FITS			
To ½-in. diameter, inc.	0.0005	to 0.001	Large
To 1 -in. diameter, inc.	0.001	to 0.002	Large
To 2 -in. diameter, inc.	0.002	to 0.003	Large
To 3½-in. diameter, inc.	0.003	to 0.004	Large
To 6 -in. diameter, inc.	0.004	to 0.005	Large
FORCING FITS			
To ½-in. diameter, inc.	0.00075	to 0.0015	Large
To 1 -in. diameter, inc.	0.0015	to 0.0025	Large
To 2 -in. diameter, inc.	0.0025	to 0.004	Large
To 3½-in. diameter, inc.	0.004	to 0.006	Large
To 6 -in. diameter, inc.	0.006	to 0.009	Large
SHRINKING FITS—FOR PIECES TO TAKE HARDENED SHELLS ½-IN. THICK AND LESS			
To ½-in. diameter, inc.	0.00025	to 0.0005	Large
To 1 -in. diameter, inc.	0.0005	to 0.001	Large
To 2 -in. diameter, inc.	0.001	to 0.0015	Large
To 3½-in. diameter, inc.	0.0015	to 0.002	Large
To 6 -in. diameter, inc.	0.002	to 0.003	Large
SHRINKING FITS—FOR PIECES TO TAKE SHELLS ETC., HAVING A THICKNESS OF MORE THAN ½-IN.			
To ½-in. diameter, inc.	0.0005	to 0.001	Large
To 1 -in. diameter, inc.	0.001	to 0.0025	Large
To 2 -in. diameter, inc.	0.0025	to 0.0035	Large
To 3½-in. diameter, inc.	0.0035	to 0.005	Large
To 6 -in. diameter, inc.	0.005	to 0.007	Large
GRINDING LIMITS FOR HOLES			
To ½-in. diameter, inc.	Standard	to 0.0005	Large
To 1 -in. diameter, inc.	Standard	to 0.00075	Large
To 2 -in. diameter, inc.	Standard	to 0.001	Large
To 3½-in. diameter, inc.	Standard	to 0.0015	Large
To 6 -in. diameter, inc.	Standard	to 0.002	Large
To 12-in. diameter, inc.	Standard	to 0.0025	Large

* The limits given in the table can be recommended for use in the manufacture of machine parts to produce satisfactory commercial work. These limits should be followed under ordinary conditions. Special cases should always be considered, as it may be desirable to vary slightly from the tables.

plan of allowing correct limits, but we have to hold the lathe to the limits given. By so ıed product free from all tool marks and at ninimum cost.

r some samples of commercial grinding taken ;he purpose of giving an idea of what can be y, as well as to give some definite data as to it is perhaps not possible to give a rule that

LIMIT GAGES FOR LATHE WORK

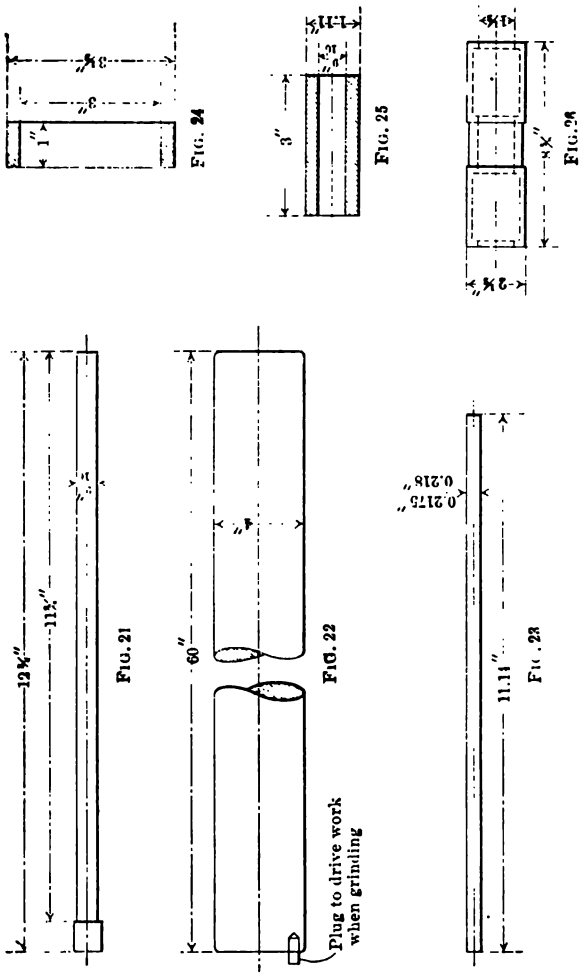


Size	Not Go On	Go On	Size	Not Go On	Go On
	Inches			Inches	
15/16	0.9455	0.9495	1 1/2	1.508	1.512
1	1.008	1.012	1 17/32	1.5705	1.5745
1 1/16	1.0705	1.0745	1 1/2	1.633	1.637
1 1/8	1.133	1.137	1 19/32	1.6955	1.6995
1 3/16	1.1955	1.1995	1 5/8	1.758	1.762
1 1/4	1.258	1.262	1 21/32	1.8205	1.8245
1 5/16	1.3205	1.3245	1 11/16	1.883	1.887
1 3/8	1.383	1.387	1 23/32	1.9455	1.9495
1 7/16	1.4455	1.4495	2	2.008	2.012

plates should suggest ideas that will help in well and as cheaply as this has been done in ɔn enough pieces of any one kind are to be pecialize to a higher degree than can be done ork, and better results may be obtained than

commercial grinding given in Figs. 21 to 26 illus- under actual working conditions in commer- of pieces indicated, which are of various mate- A reversal of the usual rule, where economy is

TABLE 3 EXAMPLES OF COMMERCIAL GRINDING



Wheel Used	Norton, Alundum, Carborundum, No. 46, grade 24	Alundum, No. 3546, grade K	Alundum, No. 38, grade 5, elastic	Alundum, No. 38, grade 24, elastic	No. 46, grade K	60, grade
Peripheral Speed of Work, Ft. per Min.	35	35 roughing; 60 finishing	35	100	55	75
Travel of Work, In. per Min.	96	48 roughing; 30 finishing	13	By hand	37	30
Peripheral Speed of Wheel, Ft. per Min.	7000	6000	5500 to 6000	5500	6500	6000
Amount of Stock Removed, Diameter	0.012 in. roughing; 0.002 in. finishing	0.025 in. roughing; 0.005 in. finishing	0.005 in. roughing; 0.001 in. finishing	0.018 in. to 0.020 in.	0.010 in. to 0.012 in.	0.020 in. to 0.025 in.	0.012 in. to 0.015 in.
No. of Pieces Completed per Hr.	13	3.5	15	10	20	54	32 / 1 man	59 / 2 men*
Required Limit	Standard to 0.00025 in. small	Standard to 0.001 in. small	Standard to 0.0005 in. small	Standard to 0.0005 in. large	Standard to 0.0005 in. large	Standard to 0.0005 in. small	Standard to 0.0005 in. small
In Lots of	100	50	500	200		200	100
Remarks	21 roughed; 35 finished per hr. Handled twice	7 roughed; 7 finished per hr. Handled twice	Handled twice for roughing and twice for finishing				*A man operates the machine and a helper puts the work on and off the arbor

gained by having one man operate more than one machine, is shown in Fig. 26, where work is most economically produced by using two men to run one machine, that is, having one man to operate it and a helper to drive the work on and off the arbor. All other data are based on one man to a machine.

39 These pieces passed inspection within the limits given. The average loss from work of this class coming below the required limit or being otherwise spoiled is less than $\frac{1}{4}$ of 1 per cent in our grinding department.

40 Figs. 27 to 33 are each notated to show the peculiar features that exist in the work, together with the data that may be of help in deciding upon other work of this class.

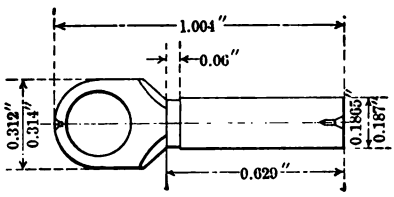


FIG. 27 SEWING-MACHINE PLUNGER—CASE-HARDENED

These pieces are ground at the rate of 145 per hour. Only a small amount, 0.006 in., is taken off to prevent grinding below the case-hardened surface. Ground on No. 11 plain grinding machine. As this piece is only about 1 in. long it is quite difficult to handle, and this somewhat reduces the output.

An elastic wheel, 36 grade 5, is used; speed of wheel, about 6000 ft. per min.; speed of work, about 35 ft. per min.

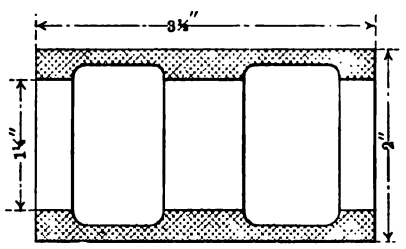


FIG. 28 BRONZE BUSHING

These bushings are ground at the rate of 30 per hour. Ground on No. 12 or No. 14 Plain Grinding Machine.

About 0.020 in. of stock is removed from the diameter. A 54 grade M American wheel is used; speed of grinding wheel, about 6500 ft. per min.; speed of work, about 70 ft. per min.

from the diameter. A Norton wheel, 3556 combination L, is used.

Speed of grinding wheel, about 7000 ft. per min.

Speed of work, about 55 ft. per min. Ground on No. 11 Plain Grinding Machine.

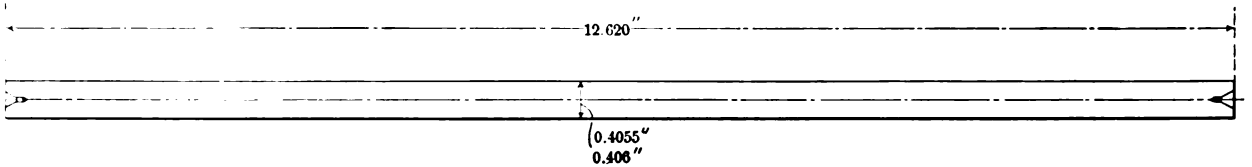


FIG. 30 SEWING-MACHINE SHAFT—CASE-HARDENED

These pieces are ground at the rate of 15 per hour. They are turned end for end for dogging in both the roughing and finishing operation; thus they are handled four times to complete. Only about 0.006 in. is left for grinding to prevent grinding under the case-hardened surface. These shafts are rough ground where there is so small an amount of stock for the purpose of breaking the scale the entire length before finishing. They are held to a limit gage ("Go on" and "Not go on"), and must be ground straight. An elastic wheel 36 grade 5, is used.

They are run through in lots of 500.

Speed of wheel, about 6000 ft. per min.

Speed of work, between 30 and 35 ft. per min.

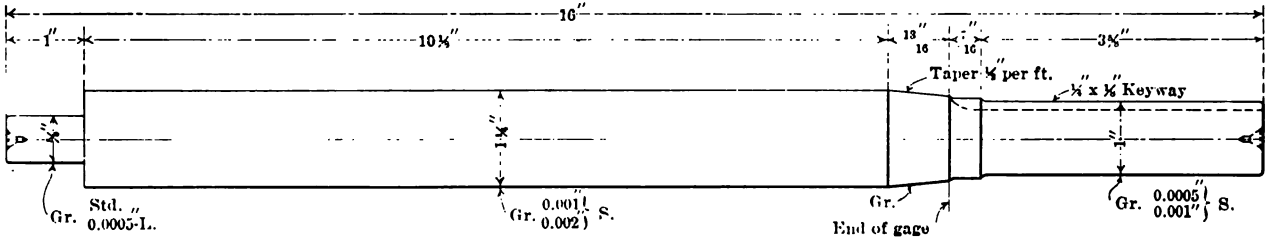


FIG. 31 SHAFT OF MACHINERY STEEL

These shafts are ground at the rate of about 5 per hr. They cannot stand heavy cuts on account of having a small diameter at one end. The taper is ground to a gage and must be concentric. Each piece is handled four times before it is finished.

Speed of grinding wheel, about 7000 ft. per min.

Speed of work, about 65 ft. per min.

Ground on No. 12 Plain Grinding Machine.

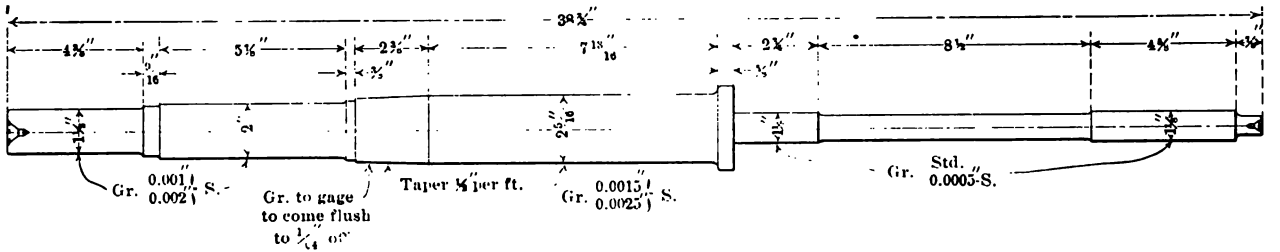


FIG. 32 SHAFT OF MACHINERY STEEL

This is a very difficult shaft to grind on account of the small diameter at one end, which gives a very poor support for grinding the larger diameters. It therefore takes about 1½ hr. to finish one shaft.

The 2 7/16-in. diameter is roughed out first so that a back rest can be used. Each shaft is handled 6 times before it is finished, and from 0.015 in. to 0.018 in. of stock is taken off.

Speed of wheel, about 7000 ft. per min.

Speed of work, about 45 ft. per min. Ground on No. 12 or No. 14 Plain Grinding Machine.

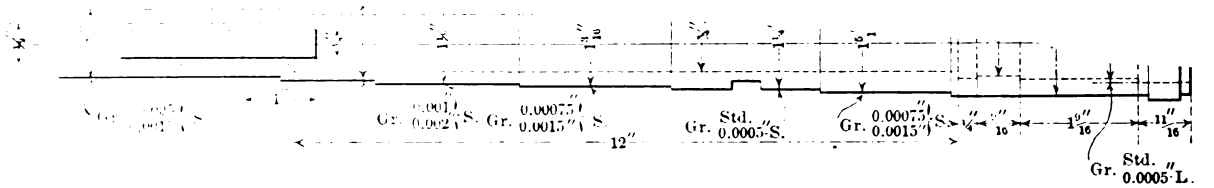


FIG. 33 SPINDLE OF UNION DRAWN STEEL—CASE-HARDENED

This spindle is ground both externally and internally. It is rough ground and then finish ground all over. A Monarch wheel 46–2¼ or a Norton wheel, 3846 grade K, is used. A very fine finish is produced. Note hole running entire length of spindle, also where cut away near small end and near middle, all of which adds to the problem of grinding.

One man grinds these spindles in lots of 50 in a little less than ½ hr. each; actual time, 50 in 24 hr. From 0.015 in. to 0.025 in. of stock is left on diameter for grinding and 0.003 in. or 0.004 in. is left for finish grinding. These spindles are ground internally on two diameters to a very close limit. These two holes must be exactly concentric and are therefore ground at one setting, at the rate of 3 per hr. Each spindle is handled 12 times before completion.

Ground on a No. 11 Plain Grinding Machine, and on a No. 2 Universal Machine for internal grinding.

No. 1301*c*

ɪN GRINDING METHODS

M. W. Hanson, Hartford, Conn.
Member of the Society

ːst, perhaps the oldest, means for reducing mate-
giving it the desired shape, is by grinding. Our
ːir stone axes and arrow points against a rock,
k and forth. The next advance in grinding was
ng of a stone on an axle turned by a crank. It
that by having water running on a stone, the
ne faster. This discovery was probably made by
ɪt time nobody would have thought of the reason
re obtained.

l then advanced to a point where the grinding
a fixed position, but the piece to be ground was
the operator, and by manipulating it at different
ɪg surface, a shape was obtained which met the
ably well. The art seems to have remained at
ɪries and not until the lathe and other machine
ː for a long time was it thought to hold the piece
sition against a revolving grinding member also
on.

machine as now used is of comparatively recent
ɪemory of men now living. The first grinding
of modern methods of grinding were made in
ːa, but it is in America that they have reached
ɔment.

ɪ of emery wheels made it possible to make fairly
grinding processes. At first very little work was
be machined and filed. The process of grinding
ːs of hardened steel, but after awhile it was dis-
ːned pieces could be machined and finished more

ɪal Meeting, New York 1910, of The American Soci-
ɴGINEERS.

accurately and cheaply by the grinding process than by finish turning and filing.

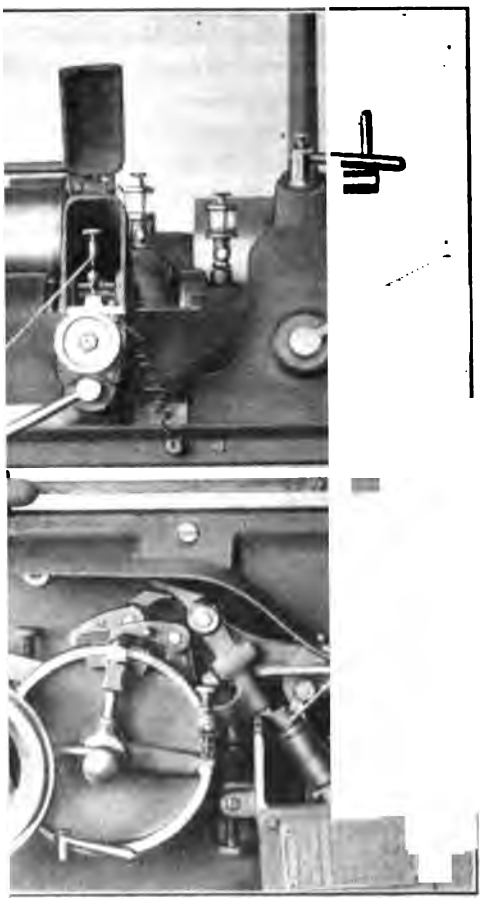
45 The grinding machine for cylindrical surfaces was developed to meet all strains and forces due to the cutting power of the shellac emery wheel; but when corundum and carborundum wheels were put in use it was found that the machinery was not quite strong and heavy enough to resist their cutting power or to resist the vibration. Within the last few years great improvements have been made not only in the cutting quality of grinding wheels, but in the design of the machines themselves; in fact, grinding machinery has become a formidable competitor of the lathe and milling machine and seems to be quite up to the cutting capacity of the wheels.

46 The designers of grinding machinery have had a good many problems to solve. Different materials require different speeds and on the modern grinding machine there must be various speeds for the grinding member as well as for the traverse movement of the work; and for the revolution of the work in the case of the cylindrical grinder. Machines must be designed with water pumps, and the working parts must be protected from water as well as from the grit which comes from the grinding wheel. The grinding member usually moves at a high rate of speed and must have carefully designed bearings which will run freely, yet not allow any back lash, as true surfaces can only be obtained when the work and the reducing member move against each other in fixed positions. Most of these difficulties have been met and further refinements are constantly being made. I will give a few illustrations of such improvements further on.

47 The grinding machines now used can be divided into two large groups; machines for cylindrical grinding and machines for grinding flat surfaces. Cylindrical grinders are well known and have been highly developed by four machine-tool builders in this country. The other style of grinder, the surface grinder, is best known as a planer type machine, with a wheel grinding on its periphery, and fed across the surface in much the same manner as a tool is fed across the surface on a planer or shaper. Another type is the vertical surface grinder with a cup-shaped wheel working in much the same manner as an end mill on a vertical milling machine.

48 In doing work on lathes or milling machines, it is comparatively easy to reproduce several pieces to the same dimensions by adjusting the machine to a size. This is possible because the reducing member, which is the turning tool, will resist wear for a considerable length of time without making any difference in the size of the work.

this is more difficult since the reducing
ing away at a rapid rate. For very close
ljust the machine for every piece to be
quires skill and time.



SIZING ATTACHMENT FOR CYLINDRICAL GRINDER, AND OPERATION OF WHICH THE FEED IS CONTROLLED

Fig. 34 are of such construction that they
, no matter how much the reducing mem-
work has reached the desired size, which
itable adjustments, the machine will auto-

matically throw out the feed and new pieces can be put in, one after another, and these will be automatically ground to practically the same diameter, say within one-quarter of a thousandth of an inch.

50 This result is brought about by controlling the feed of the reducing member electrically. The mechanism of the controlling device is shown in Fig. 35. The lever A carries a smooth-pointed diamond which bears against the work W at a and at its other end is the point b for electrical contact. There is a second lever C with contact points at c, and a contact point d is attached to the frame. As the diameter of the work is reduced the long arm of lever A drops until point b touches the contact point at c, which, through an electrical connection changes the feed of the wheel and causes it to move against the work at a slower rate. When the work has been reduced to size,

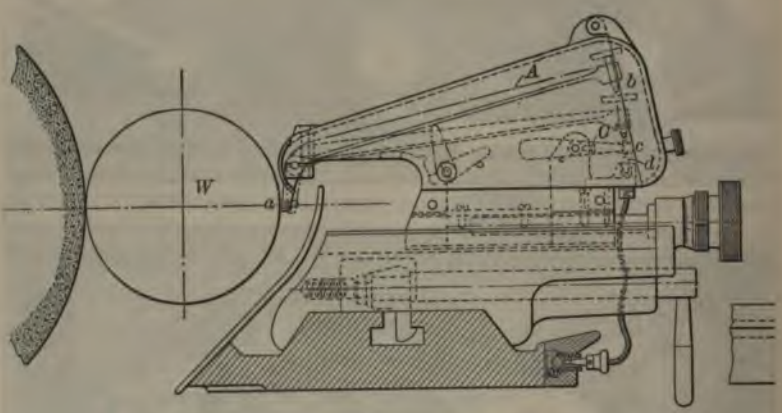


FIG. 35 VIEW SHOWING MECHANISM OF SIZING DEVICE

lever A drops still further, carrying with it lever C, until an electrical connection is established between points c and d which throws out the feed.

51 It will easily be seen that an operator can manipulate more than one of these machines and that by their use less skill is required to get uniformity of size. In this design the size of the work is controlled by contact with the work itself, which is the preferable way, but the same results could be obtained by contact with the reducing member. This, however, would be more difficult because of the coarseness of the reducing member and its ability to wear away the contact point faster than does the work.

is the back rest, shown in Fig. 36. It support the work as rigidly as possible

[illegible] IN PLACE; ALSO OVERHEAD DRUM, WHICH [illegible] GRAL PART OF THE MACHINE

the work is constantly being reduced in be kept in contact with the work either

by hand or automatically, and hand adjustment requires considerable skill. In the device shown it is accomplished automatically, the back rest advancing at exactly the same rate that the diameter of the work is reduced by the wheel; and as it advances, the back rest member is locked solid, making it impossible to spring it by the wheel pressing against it when traveling across.

53 This view also shows the overhead drum, which is made an integral part of the machine. The main drive for the machine is

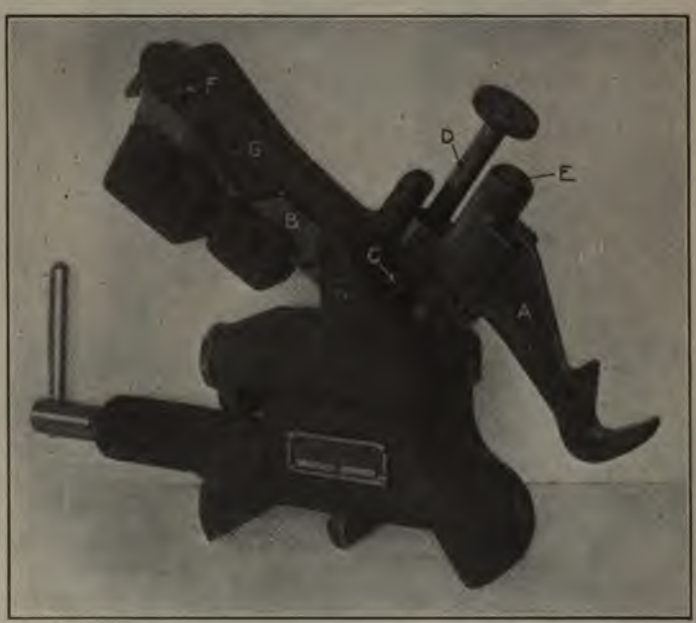


FIG. 37 BACK REST, DESIGNED TO FOLLOW THE WORK AS IT REDUCES IN DIAMETER AND TO LOCK AUTOMATICALLY AGAINST THE PRESSURE OF THE WHEEL

by single belt to a short shaft at the base, from which the drives for the wheel and the drum are belted. This arrangement avoids a complicated overhead countershaft and enables the operator to change the speeds and manipulate the various mechanisms with ease.

54 The operation of the back rest will be understood from Fig. 37. The arm *A* which supports the work is held in contact with the work by means of the weighted lever *B*, fulcrumed in the frame.

FIG. 38 SURFACE GRINDER, 25 IN. BY 60 IN., 30-IN. WHEEL; DRIVEN BY A 40-H.P. MOTOR

against the adjusting screw *D* at point C and causes the arm to slide in an upward direction on pin *E*. As lever *B* is depressed a roller *F* travels downward into the V-shaped space formed by the upper surface of lever *B* and the lower surface of the casting *G*, this roller preventing any upward movement of the lever and consequently any movement of the back rest away from the work.

55 As said before, surface grinders have usually been made with the wheel grinding on its periphery and in some instances it may be necessary to continue to do work on this principle, as grooves and irregular shapes sometimes have to be ground and the thinness of the wheel makes it possible to get into narrow places; but when flat surfaces are wanted, the cup-shaped wheel has taken a foremost place in grinding. The wheel covers the whole width of the work at once and water is forced through the center of the spindle, centrifugal force throwing the water outward and compelling it to pass between the work and the wheel. It is astonishing with what rapidity work can be reduced to a flat surface under this process.

56 This method of grinding would never have been successful if it had not been for the advancement in wheel making. The wheel problem in connection with the machine has been most difficult. It has been found very essential to select the right kind of wheel for different classes of work and for different materials. For grinding steel, either hardened or soft, corundum wheels have proved the best and for grinding cast iron the carborundum wheel has proved the best. The different degrees of hardness must be taken into consideration when the width of the surfaces to be ground varies.

57 The makers have decided to place on the market a much larger machine of this type than they have made before, shown in Fig. 38. This machine has a table stroke of 6 ft., and can grind a piece 6 ft. long and about 25 in. wide. It can also grind circular rings and disc surfaces up to 30 in. in diameter. The wheel has a diameter of 30 in. and the whole machine is driven from a single belt by a 40-h.p. motor. As this machine has just recently been built, its capability is not fully known, but for work that has already been tried it shows very encouraging results. For such work as grinding guide bars, slide valves and link motions for locomotives, large stamping dies such as are used in electric works, facing automobile cylinders and automobile engine frames, I believe it will show its superiority over any other method by several hundred per cent. In one of the trials a surface of cast iron, 6 ft. long and 20 in. wide was reduced in thickness 0.01 in. in five minutes, leaving an excellent finish and an exact

NG: No. 1, Pressed Steel, 15 per hour; No.
HOUR; No. 3, Malleable Iron, 12 per hour

flatness. In fact when tested no point in the surface showed out of true more than 0.0005 in. In grinding steel this type of surface grinder produces chips that look very much like metallic wool, which seems to indicate that when a cupped wheel passes over the work, the chips are made by the outer edge of the wheel in the same manner as chips produced by the outer edge of an end milling cutter. If the chips were made underneath the broad contact surface of the wheel there would not be room for them to curl up in the small places which are left

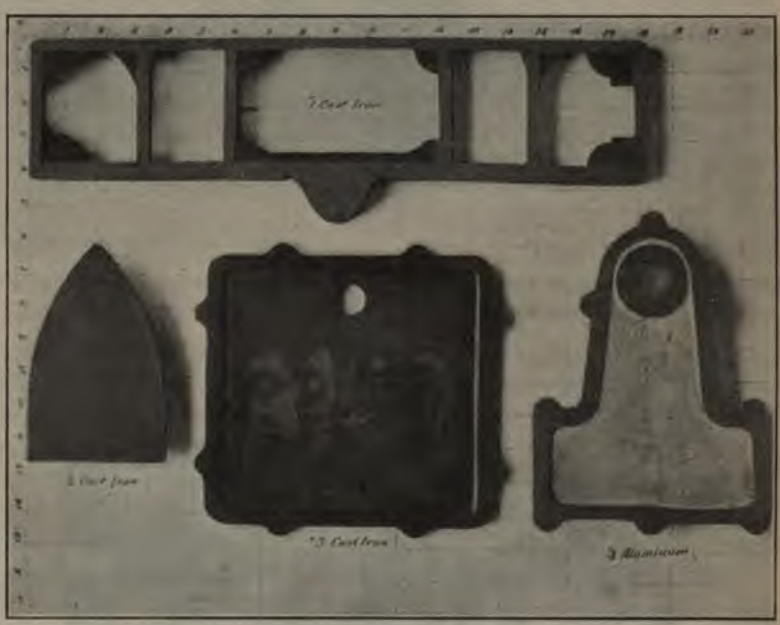
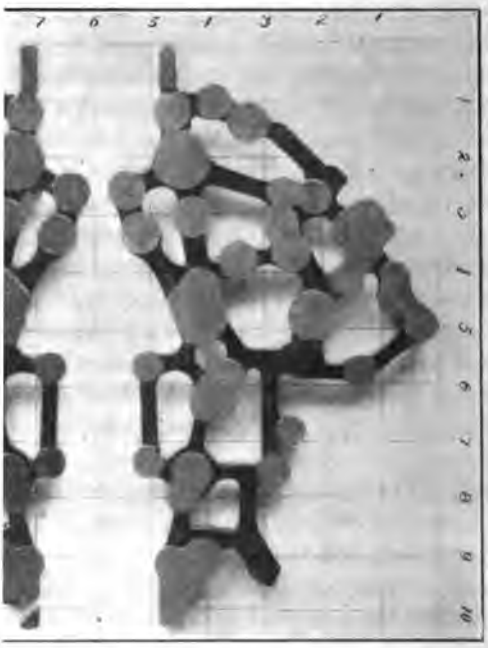


FIG. 41 EXAMPLES OF GRINDING: No. 1, CAST IRON, 15 TO 20 PER HOUR; No. 2, CAST IRON, 60 PER HOUR; No. 3, CAST IRON, 25 PER HOUR; No. 4, ALUMINUM, 30 PER HOUR

between each cutting particle of the grinding wheel. The large surface in contact with the work simply smooths the surface.

58 The table on these machines is provided with different feeds. It is difficult to make an exact rule as to what feeds to use for different materials, but the operator can determine this by running the machine a few minutes. The difficulty lies in the fact that wheels supposed to be made to the same specifications, vary considerably

d has to be regulated not only to suit the
also to suit the cutting ability of the wheel
t time it is safe to say that grinding machin-
he cutting capacity of the wheels and there
essential changes until the grinding wheels
velopment.
veral photographs are shown of work which
ical cupped-wheel machines. In some in-



NDING: ADDING MACHINE FRAME, CAST IRON, 15 PER HOUR

oduction of small gun parts, like hammers
as been done from fifteen to twenty times
ed and it has a smoother and more accurate
y true where the surfaces are not too wide.
the capacity of a grinding machine having
ing flat surfaces, compared with a grinding
rinding on its periphery and working on the
worth while to note the following:

61 The traversing speed of the work or the work table can be assumed to be the same. If a piece is 6 in. long and 3 in. wide, the machine grinding on its periphery will take about 48 strokes to cover the surface, assuming $\frac{1}{16}$-in. feed for each stroke. The cupped-wheel machine will do the same amount of work with one stroke or in about $\frac{1}{24}$ the time. These proportions are essentially true on hardened steel or on any kind of work where a nice finish is required.

No. 1301*d*

SION ON GRINDING

e papers on this subject read before the portune. Of all engineering subjects, that of most neglected; and of all machine tools, nd understood than the grinder. This does e not a few men who know how to get good , but that most men look upon it with sus- ng to acknowledge that grinding is a good t not knowing anything about the subject be expected to be very enthusiastic.

n written on grinding and grinding machines, they have been printed on thick paper with es between the lines cannot hide the absolute ween the covers. Some articles have been which give definite information along certain nply tell what has been done, not what can be done.

n does not apply entirely to some of the liter- akers of grinding machines and wheels. In on is called to the fact that the grading and kind of abrasive material and grinder used, ed of the work, the feed and interrelation ms, as also the material, hardness, stiffness rk, have effects on the final result, and that oned items and several others not mentioned n as any of the others is changed, but how or ed. These pamphlets are perhaps superior r to some which describe other kinds of tools opinion the literature used by the makers of heels is the best written on this subject; but y scientific standpoint, nothing yet written

Meeting, New York 1910, of THE AMERICAN SOCI- NEERS.

can be called good. My object in saying this is to point out that a void exists, that there is an almost complete lack of definite and accurate information as to grinding.

I believe that the main reason for this condition of affairs lies in the fact that no extensive experiments have been made in regard to grinding, except, perhaps, by the makers of wheels and grinders; and to them the result of their experiments is valuable private property. All our machine tools have passed through the same stage, and most of them have only partly emerged, if at all; but practically all machine tools, with the exception of grinders, have a relatively long history, and the knowledge which we now have on the subject of various machine tools has been gradually pieced together from an immense amount of experience and a few experiments. The grinder has not yet reached this point and this, in my opinion, is the main reason why so little definite knowledge exists in regard to it.

We know something about the lathe and we can easily get more knowledge because all the elements which enter into lathe work, the action of the machine, the action of the work, and the tool, are fairly well known to us. A piece of steel is a very definite thing. Its shape and hardness can be determined in a relatively simple way. The way in which the tool is held in the lathe is very definite and obvious.

On the other hand, it does not seem possible, at least at the present time, to produce wheels which are so nearly duplicates of each other as two steel tools cut from the same bar and hardened in the same way; and even that, we know, is not very easy. Add to this the fact that there is no uniformity in the grading of wheels, and it will be hard to blame the average mechanic for trying the first wheel that comes to hand.

Though all literature on the subject of grinding wheels emphasizes the fact that great care should be taken in the selection of a wheel, and that each particular kind of work and finish calls for a different kind of wheel, yet the final recommendation is that such and such a wheel is on an average the best for such and such a material. Where then shall the mechanic find the information which enables him to select his wheel? Is he supposed to try all the wheels in the shop and make observations and select the best one for his job? It seems to me that the entire subject is in a state of confusion, except perhaps to a few initiated ones. Great stress is laid on the necessity of the proper relation between speed of wheel and speed of work. My experience has shown me that every mechanic has his own rule for the

ar as speed of the wheel is concerned, how is
n at the proper speed when he is confronted
nly two speeds, and with a wheel which varies
haps 8 in. or 10 in. Some of the examples
nted here give wheel speeds of 7000 ft., others
only 7 per cent. This 7 per cent seems to be
ut what grinding machine enables us to get
he way down for wheels ranging from 18 in.

laid on the proper relation between width of
l; in other words it seems to be necessary to
revolution of the work; yet how many grind-
ce the traverse of the table a function of the
of the work, such as the traverse of a
function of the number of revolutions of the
riticism of the makers of grinders, for with-
e been developed more rapidly in the last 20
other machine tool, so that credit rather than
akers of these machines. The object of this
call attention to the many and wide gaps left
the subject of grinding. I believe that we
undation for such knowledge. A great many
ts and theories are missing. That this is so
ly by the three papers presented here. All
e done much to improve the grinder and to
per methods of grinding, and who are certainly
tements as definite and authoritative as could
There is not one instance in all the examples
where the speeds or feeds, or any of the other
, nor is there such an analysis in the examples
We see simply final results, but the information
us to duplicate the performance or to improve
e typical of the condition in which the whole
at the present time.

a great help in the shop and one of the greatest
indisputable among progressive men of today.
ealize that the grinder is not taking work away
ther that in former years the lathe was doing
r should have done.

able that the vertical surface grinder lagged
redit is due to the men who developed this type

to its present efficiency. It is quite natural, when a new type or construction of machine enters the market and when its success is proved, to find enthusiasm as to the possibilities of such a machine. Such is the case almost universally; and, as a rule, it reacts against the new machine, because it necessarily leads to disappointments.

Mr. Hanson compares the performance of a vertical grinder with work done on a milling machine; but he does not specify the kind of milling machine on which the work was done, nor the method employed. There is no doubt but that certain work can be done more quickly on the grinder than on the milling machine, and that other work can be done more quickly on the milling machine than on the grinder. For instance, frail work with relatively little metal to be removed and where nothing but a flat surface is to be produced is an ideal job for the vertical grinder. On the other hand, stocky work with much metal to be removed is better adapted to the milling machine. If a comparison is to be made between the two machines, it should be in relation to work which can be done on either of the two machines. Then it should be tried out on both machines, each one the best of its kind, with fixtures adapted to the machine, and according to the best methods which can be devised for these machines.

It is entirely beyond my comprehension how the milling operation on small pieces, such as hammers and triggers of guns, could be done 15 or 20 times faster on any kind of machine than it can be done on the milling machine, because such pieces can be milled as rapidly as the operator can put them in the machine and this is the best that could be done by a grinder or by any other type of machine. This is no attempt to detract from the value of the vertical grinder, and least of all do I mean to say that Mr. Hanson favors the grinder at the expense of the milling machine. What I wish to point out is that no comparison should be made between the two machines except on the basis of selection of the kind of work adapted to each of the two types.

My connection with the Cincinnati Milling Machine Company leads me frequently to make recommendation as to the type and size of milling machine required for certain kinds of work, and it occasionally happens that I recommend the vertical grinder, but it has been my experience that wherever a grinder as well as a milling machine could be used for a certain class of work the output on a milling machine would exceed that of the grinder.

Flatirons, such as shown in Fig. 41 of Mr. Hanson's paper, were done at the rate of 160 per hr. on the milling machine, with a slightly

obtained on the grinder but sufficient for
rate of 105 per hr. with a finish of the same
ı the grinder. The superior results are due
lling machine is capable of removing more
'acility and that a fixture can be employed to
nsert the work while the machine is milling.

n Par. 56 Mr. Hanson refers to the impor-
he right kind of wheel. It has been the writer's
of the builders of grinding machinery this
ood. Even some grinding machine builders
relatively little importance and often send
ɒped with grinding wheels wholly unadapted
grade for the work they are expected to do.
resulted in the rejection of the machine. If
tood the principles governing the selection
ıd consulted an experienced wheel maker, he
ɛels which would have caused the machine to
ɔn. A case of this sort recently came under
lisc-wheel surface grinder had been furnished
high-speed steel pieces. The customer found
his pieces flat, and rejected the machine.
ɒped back, a wheel maker happened to visit
ɒecame acquainted with the facts. He sup-
'hich ground the pieces perfectly flat and the
.ccepted and is still in use on this job. Cases
occurrence.
ys that grinding is an art. An element of
lection of grinding wheels. There are three
ider.
ıaterial of which the wheel is made. No
discovered which is equally efficient on all
crystals of different abrasives differ greatly
oughness. To cut different metals in a lathe,
grind the cutting tool to different shapes.
ive crystals are of such shape and structure
fficient on different kinds of metals. For as
each particle of abrasive is a minute cutting
of work is being done then, it is necessary to
de of different abrasives if a high degree of
ed.

Second, we have to consider the hardness of the wheel, and by this is meant the tenacity with which the grains of abrasive are held together by the bond. Some metals exert a greater tendency than others to tear the particles of abrasive from the face of the wheel. It is therefore necessary to use wheels of the right hardness, for if the wheel is too hard for the work it is intended to do, the abrasive grains will remain in place after their cutting points have become dulled; and if the wheel is too soft the grains will be torn away before they have done the proper amount of work, and the wheel will be wasted. Where the area of contact is large between the wheel and the work, as when grinding with a cup wheel or a cylinder wheel, the hardness has to be adjusted to the work with extreme accuracy.

Third, is the consideration of the coarseness of the grains of which the grinding wheel is made. Generally speaking, coarse wheels will cut faster than fine ones, but will give a poorer finish. To combine in a degree the rapid cutting properties of coarse wheels with the good finish of fine ones, wheel makers now sell combination wheels made of three to five numbers. For instance, a No. 24 combination wheel may be made of mixed grains ranging all the way from No. 24 to No. 100. Such wheels were first used extensively for crankshaft grinding in automobile factories and are now employed for a great variety of purposes. In fact, some wheel makers use a mixture of different grains in nearly all their wheels.

It might seem that the experienced wheel maker could prepare a list to show the combination of abrasive, hardness and coarseness, which could always be the most efficient for grinding all of the materials ordinarily met with in the grinding room. This, however, is not the case, because the conditions vary essentially in every plant. Take the single case of grinding cast-iron automobile cylinders. One manufacturer of cylinder-grinding machines regularly carries for his customers twelve different kinds of wheels of one size. This variety is required for several reasons. In the first place there is no standard of finish. One plant prefers a medium finish and rapid production, while another insists on an absolutely smooth bright finish. There is great variation in cast iron. Even individual castings in one lot vary in hardness, and castings from different foundries often require very different wheels. There are also differences in practice, as in the speed with which the work and the wheel are revolved, the rate of feed, etc.

In spite of this diversity of conditions, each plant can readily select wheels adapted to its own requirements provided the principles of

l. In every works one man should be given
of grinding wheels and a list prepared showing
r each class of work on each machine. The
nd feeds may be left to the foreman or the

rs usually keep records covering the perform-
at variety of uses and conditions. From these
of the principles of selection, they can usually
heels of high efficiency provided full informa-
the conditions of use.

These papers have clearly shown that the
lindrical grinding machine must be seriously
luction engineer and they have also made clear
ling wheel is not the sandstone or emery wheel
a highly developed cutting tool which has been
d for the various conditions under which it is
e metals it is to cut.

been made in the cutting materials used in
The wheel maker first used quartz, emery and
ter days have seen wonderful skill in the use of
This has given us improved abrasives which
g wheel more efficient.

y the wheel is not used up to its cutting capacity,
that but few grinding machines are correctly
igned. The wheel maker has found that the
; grain itself must also be suitable for the work
s intended. For instance, an abrasive made for
ot be at all efficient in a larger wheel on a heavy
abrasive used on the end of a slim internal
eak structure in order that it may keep sharp
ssure of this grinding operation; while this
not do at all under the impact of heavy work.
ve on cast iron may not be at all efficient on
er must have at his command not only the art
ent grades of hardness, but must have a full
ives if he would be in a position to make the
purpose.

led attention to the chips from a modern grind-
hose from an emery wheel, which show clearly

Co., Worcester, Mass.

the difference between the wheel of today and that of yesterday. The wheel maker finds that he must not only suit the size of his cutting teeth and the strength with which they are bonded together to the particular metal that is to be ground, but that he must also calculate the additional strength of the bond necessary to withstand the vibrations brought about by mechanical defects in the design of the machine on which the wheel is mounted. He must still further consider the strength of bond in relation to the number of cutting teeth in contact with the work; as for instance in grinding on the end of a cylinder as with Mr. Hanson's surface grinder. Owing to the large surface of contact each grain has more work to do in a given time and therefore dulls more quickly than if the grinding were done on the peripheral surface of a wheel and the wheel must be of such abrasive temper and so bonded that it will dull slowly. On the planer type of grinder, the same work could be done by a harder wheel for the reason that each cutting tooth has less to do and therefore remains sharp longer.

In reading Mr. Hanson's paper, I wondered whether he had ever considered a surface grinder of the planer type using wide wheels with rapid feeds and greater depth of cut. The making of uniform wheels from 12 in. to 60 in. in width is within the limits of the wheel maker. Grinding by the cupped-wheel system will always give the mineral wool that Mr. Hanson describes, because the depth of cut of the wheel on such a broad contact is so small that only hair-like chips are produced. Grinding on the periphery of a wheel on the same metal will always give a larger chip, because of the greater depth of cut.

I firmly believe that a machine of the planer type could be constructed which would use less power, would be more efficient in wheels, and would do faster work than any surface grinding machine yet devised, and that not until this has happened, will the abrasive wheel be brought to its full efficiency on this kind of grinding.

HENRY HESS. My views differ from those of Mr. DeLeeuw since I believe that the grinding machine of today is probably as far advanced as any other machine tool, although it is true that there is no treatise which gives exhaustively the information necessary to secure the maximum benefit of grinding. The same thing is true, however, of the lathe, the planer or any other cutting tool. The grinding machine handles work of very great variety, finishing it to within less than 0.001 in. of the size desired and doing it so cheaply that the grinding machine competes with the foundry, as proven by some of the crank-

Norton's paper. To expect that any manu-
ın give directions to cover this broad field so
ɔr to make the best use of the machine is out
ɛr can the manufacturer of the lathe or the
ɛe information to the users of these machines.
ıe machine and develop its use so as to obtain
r each condition.

first grinding machine used in machine
untry was built by Joseph R. Brown, with
at the time. We were struggling to make
as accurately as required and the lathe with
for this work was an antiquated method.
plied his scientific skill to the problem, he
irely new ground and his achievement has
trial progress of the United States than any
ɔf. We are now able to turn out hardened
ıcy and at very low cost. Mr. Norton is
ıtement that the engineering faculty of this
ɔpreciated the fact that the grinding machine
ɣork, but is one of the most economical ma-
automobile industry is using it extensively
est work at very low cost.
paper the snap gage with a limit of 0.004 in.
ɔmically, the important thing is to give the
ɔmmensurate with the results required, but
instance in our factory where we grind many
omobiles in which the limit of 0.004 in. is
at we can grind very cheaply to within the
n some cases even as close 0.0005 in. For
nit on the camshaft 30 in. long and $\frac{3}{4}$ in. in
at one end and ground nearly up to that
)0 or 1000 of them the operator begins to
when the two grindings meet they blend so
to tell which end has been dogged. A man
ıachine shop practice saw this operation and
require a very expensive man to do such
s able to tell him that the man who was doing
had come from a Michigan farm five weeks
ɤ a grinding machine from a lathe when he
This illustrates most forcibly Mr. Norton's

claim that engineers are not fully advised on the cheapness and economy with which the grinding machine can be operated.

OBERLIN SMITH. The remarks of Mr. Leland in regard to the dogging of the work bring up the fact that not enough attention is paid to the avoidance of dogging by using a square driving center on one end. The work can be fitted to this by using a square center punch forced into the usual round countersink. This enables a piece to be turned or ground along its entire length without being taken from the machine and turned around.

Where a dead, rather than a live center is used at the driving end, as in most grinders, the work can be provided with one or two small holes or grooves, a little outside of the countersink, into which can enter pegs or jams projecting from a sleeve surrounding and revolving upon the dead center. This sleeve would be virtually a part of the driving chuck.

CLOSURES[1]

C. H. NORTON. No one knows everything about grinding and the thought underlying my paper was rather to censure the engineer for not knowing more about it and not helping to find out about it. The common mechanic is doing the grinding and it is not scientific. We ask the engineer to tell us about it. We simply know how to grind economically, but we have not time to study the scientific aspects of the problem. The automobile would not be in existence as it is today if we stopped to consider the points brought out by Mr. DeLeeuw. It is time the scientific engineer came in with us.

It is not necessarily true that a coarse wheel will cut a coarse surface. A very coarse wheel with hard enough bond will grind a chilled roll so that the surface reflects, and the particles may be as large as a finger tip.

Mr. Hanson speaks of the difficulty of sizing with the grinding wheel because the wheel wears. Difficulties are always relative to our knowledge of the case in hand.

In regard to the knowledge of grinding and grinding wheels being private property, it is the effort of grinding machine makers everywhere to make that property public, and the only reason that we do not succeed in this is that you do not let us go to your places with grinding machines and let us show you how it is done.

[1] B. M. W. HANSON did not desire to present a closure.—EDITOR.

elieve, produced a machine which is very
cupped wheel for certain things is an ideal
ve it is right for everything. To remove a
ccording to our experience, the periphery of
, and in the comparison he makes I think he
t it is necessary to have a periphery wheel so
trokes, because if a periphery wheel were as
ground it would be possible to go across it
is done on round work, which is merely flat
le. On work that has bosses on it, however,
the cupped wheel is ideal, as it assists in
vn against the chuck and it is necessary to
member adjusted. But on a continuous
in, it is difficult to get such work flat unless
r almost every article that comes to the
ıe various theories about speeds and feeds, it
ıe speed of a wheel was very important, but
without an understanding of some of the fac-
. Certain cutting material does work best
er. In some of our work we find that our
000 ft. per minute, while some other maker,
having different inertia of parts around the
r at some other speed. The aim is to keep
operator in one case will use a certain speed
s in a given time as another operator with a
nditions are usually left to the operator
the production is increasing all the while.
different wheels, some makers are sending
ıt wheels because they must suit the whims
the commercial side and accounts for there
a good many cases.
ters, the very pith of grinding is accuracy,
a center on a spindle and revolve the spindle
acy for any length of time he is fortunate.
k whether it is done with a grinding wheel

which different-sized grains are used make a
average cut of the average grain will be
from a No. 24 combination wheel, 24, 36
otained that will represent about 60 when it
ıt of work. The minimum amount of work
he wheel is smoothed off in the meantime.

W. A. VIALL. As Mr. Norton has said, grinding is so little understood that it has to be considered an art rather than an exact science.

Precision grinding, a term which I have used with hesitation, is not a nice detail for the fine tool makers, but, as Mr. Leland brought out, a cheap way of doing work. Whether the shaft we are grinding is to be used as a shaft of a wheel or to be run in a journal, we prefer the grinding. In one case a small limit will be used and in another a larger limit, reducing the cost as much as possible. It is economy pure and simple.

The limits given in my contribution (Table 2), are not for grinding work but those to which the lathe work is to be finished for the grinding machine. Grinding machine limits vary from 0.00025 in. to 0.001 and 0.002 in., depending on the purpose for which the surface to be ground is wanted. It is evident that Mr. Leland in his discussion has misunderstood the use of the snap gage which I showed and described. The limit of 0.004 in. in these snap gages is a limit for turning the work ready to go to the grinding machine and not the limit for grinding.

No. 1302

·AS-ENGINE INSTALLATION IN ICAN STEEL WORKS

ID OPERATING CHARACTERISTICS OF NG-ENGINE UNITS OF 2000 H.P. EACH, -GENERATING UNITS OF 1000 H.P. EACH) GAS-CLEANING PLANTS

. P. COLEMAN, BUFFALO, N. Y.

Member of the Society

:ks of the Lackawanna Steel Company is located power plant to be operated in this country with In the following pages it will be attempted to of the plant, certain details of its operation and ntitative nature derived from observation and

e learned, the selection of the type of engine was on extended observation by a committee of the rnace gas-power plants in Europe. The types Cockerill, Otto, Oechelhaueser, and Koerting. engine was disregarded on account of the crank e four-stroke cycle engines were not favorably at of exhaust valve troubles which did not seem ed at that time. The engines were built by the ine Company, New York, after designs by the others, Hanover, Germany.

nd tabulation of various of these data, and other egs to acknowledge the valuable assistance of the Hugh Boyd, E. E. Kiger, George Conlee, F. C. Baker, aylor, R. L. Streeter and Harry Thompson, all of en, members of the engineering department of the pany. The experience of the author at this plant art of 1906.

nnual Meeting, New York 1910, of THE AMERICAN AL ENGINEERS.

3 At this plant 12,000 to 15,000 net h.p. is normally by gas engines operated with blast-furnace gas, the greater portion for blowing the furnaces. There are sixteen blowing engines, each rated at 2000 i.h.p., and eight electric power units, each consisting of a gas engine rated at 1000 i.h.p., direct-connected to a 500-kw. generator. Four of these units generate direct current at 250 volts, and the other four generate three-phase 25-cycle alternating current at 440 volts. All of these gas engines are of the two-stroke cycle type, equipped with twin cylinders and cranks spaced 90 deg. apart. A brief general description of the plant used in developing this power will first be given, followed by a more detailed description of the various parts.

GENERAL DESCRIPTION OF PLANT

4 The general arrangement is shown in plan, Fig. 1. There are six blast furnaces in a line extending approximately north and south. These furnaces are grouped in pairs, each pair forming a unit with reference to the arrangement of its stoves, ore bins, gas plant, and other auxiliaries. A seventh furnace not shown is now in operation, but as all of the excess gas from this furnace is burned under boilers, it does not concern the subject under consideration.

5 The blowing engines using gas are located in the two buildings, No. 2 and No. 3 blowing-engine houses. The engines in blowing-engine house No. 2 furnish air for furnaces 3 and 4. Furnaces 5 and 6 are supplied with air by the engines in blowing-engine house No. 3. The air for furnaces 1 and 2 is usually supplied by steam engines located in the north end of blowing-engine house No. 2. Considerable flexibility is secured by means of cross connections, with valves, between the various cold blast mains. The gas-driven electric-generator units are located in the south end of power house No. 1, situated east of blowing-engine house No. 2.

6 The generation of power at this plant requires three principal processes: the production of the gas by the furnaces; the preparation of the gas for use in the gas engines, involving cooling, cleaning and drying; and the development of power by combustion of the gas in the motor cylinders.

7 The general process of preparing the gas for use in the motor cylinders is as follows: the gas leaving the furnace top passes through large downcomer pipes to the dust catcher, where the heavier portion of the dirt is deposited under the action of gravity. From the dust catcher, portions of the gas pass through pipe mains respectively

oilers, and the gas engines. That portion
is cooled and partially cleaned by means
ipes and chambers through which the gas
further cleaned by passing through centri-
ter is also sprayed. From the fans the gas
s which remove the entrained moisture and
ience under a few ounces of pressure (above
e houses. That portion of gas going to the
ives no further cleaning after leaving the

owing engines in each blowing-engine house,
ers at 2000 h.p. In the power house are
000 h.p. each.

FURNACES

rnaces under consideration produce about
n per 24 hr. or about 108 tons per hr.
ut 150,000 cu. ft. per ton of iron, or say about
r. or more from the six furnaces. Approxi-
. per hr. is used for the gas-engine plant, the
in the hot-blast stoves and under the boilers.
2, located at the northern end, are smaller
; rated at about 300 tons each per 24 hr.
re: hearth diameter, 11 ft.; diameter of bosh,
There are three downcomers of steel plate
. in diameter and lined with fire brick to 45 in.
at the top of the dust catcher, which is 20
l equipped with conical top and bottom. The
bout 18 ft. 3 in. inside diameter and is about
pening to dust valve at bottom. These fur-
their rating of 300 tons each per day.
and 6 each make about 500 tons of iron per
nd 5 are alike in general dimensions. The
eter; bosh, 22 ft. 9 in. diameter; and the height
Furnace 6 has corresponding diameters of
94 ft. high.
ers of steel plate, each 6 ft. 6 in. in diameter,
le diameter, take the gas to the dust catcher,
ter, lined with 9-in. fire brick, equipped with
, and about 39 ft. deep from top gas inlet to
f hopper.

13 All of the dust catchers are provided with a suspended partition or baffle wall of firebrick, cutting off direct passage of gas from inlet to outlet; the gas having to pass under this wall and up to the outlet. The location of these furnaces is shown in Fig. 1.

PIPING

14 The general arrangement and involved main dimensions of the piping for washed gas are shown in Fig. 1. Each group of eight blowing engines is served with washed gas through a 60-in. overhead main of riveted steel plate delivering gas to a main header of 96 in. diameter situated along the wall of the engine house near the yard level. The eight 1000-h.p. engines at power house No. 1 are supplied with gas from furnaces 1 and 2 through a 30-in. underground pipe of cast iron. This 30-in. pipe is cross-connected with the 96-in. header near the south end of blowing-engine house No. 2, by means of a 42-in. overhead pipe. Gas washers 3 and 4 are connected with gas washers 5 and 6 through a 36-in. equalizing pipe as shown. Low points in the piping are provided with drains. The general arrangement of this piping deserves adverse criticism, as will be shown. No gas holders are installed or required. The length of the 30-in. main supplying the power house is about 1180 ft. The 60-in. main supplying engine house No. 2 is about 525 ft. long, and the 96-in. header at blowing-engine house No. 3 is supplied through about 415 ft. of 60-in. pipe. In this main at the south end of the engine house is a 60-in. venturi meter. The blowing-engine house header lies along the east side of the building. It is supported on the concrete work of the exhaust tunnel and is about 400 ft. long. The 8-ft. section is 255 ft. long and is of riveted $\frac{3}{8}$-in. plate. The plates of the 6-ft. portion are $\frac{5}{16}$ in. thick. A 24-in. connection is taken off for each engine on the side nearest the building. Water is drained from the header by means of an inverted siphon. The total length of piping from the washers to the engine houses is about 3800 ft.

GAS WASHERS

15 There is a gas-cleaning plant at each pair of furnaces consisting of chambers equipped with water sprays for cooling the gas and washing out a portion of the dirt, centrifugal fans also provided with water sprays, separators for removing the entrained water, and the necessary valves and piping. Symbolic diagrams, Figs. 2 and 3,

FOLDER No. 18

3 At this plant 12,000 to 15,000 net h.p. is normally developed by gas engines operated with blast-furnace gas, the greater portion for blowing the furnaces. There are sixteen blowing engines, each rated at 2000 i.h.p., and eight electric power units, each consisting of a gas engine rated at 1000 i.h.p., direct-connected to a 500-kw. generator. Four of these units generate direct current at 250 volts, and the other four generate three-phase 25-cycle alternating current at 440 volts. All of these gas engines are of the two-stroke cycle type, equipped with twin cylinders and cranks spaced 90 deg. apart. A brief general description of the plant used in developing this power will first be given, followed by a more detailed description of the various parts.

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7 The general process of preparing the gas for use in the motor cylinders is as follows: the gas leaving the furnace top passes through large downcomer pipes to the dust catcher, where the heavier portion of the dirt is deposited under the action of gravity. From the dust catcher, portions of the gas pass through pipe mains respectively

FOLDER No. 14

epresent the gene
s furnaces 1 and
ns at furnaces 3
urnaces 5 and 6

16 Fig. 2 show
Gas is taken from
s given an initial
The cool gas ther
wo furnaces. T
orming a unit c
ach other. The
ischarges it to a
rom this main ar
which the gas pa
17 The pipe le
t a point about
ater-seal d valv
n diameter, throu
filing with water
ater the gas flow
ions being useful
quality of gas.
he water is drain
18 The 70-in
bout 236 ft. in l
o fan being about
r cooling the ga
es are located at
harge a cone-sha
ps. The sprays
ipe connections
ain. The water
through a seal int
he water passes o
19 The connec
0-in. main, the c
. diameter. Ea
eans of a disc val

eme. Fig. 2 shows the washery first installed
ig. 3 indicates the arrangement of appara-
. The general arrangement of washers at
ilar to that at furnaces 3 and 4.

.S WASHERS NOS. 1 AND 2

chematic arrangement of this cleaning plant.
ıst catchers through horizontal pipes where it
ıg and washing by means of water sprays.
es to four fan washers located between the
ıns are normally operated in pairs, each pair
ıg of the two fans operating in series with
ın draws cool gas from the main supply and
vashed main. The second fan takes its gas
harges it to the second-washed main, from
the 30-in. gas line and to the power house.
from dust catcher to fans is 70 in. in diameter.
ay between the fans and the dust catcher a
ıted, consisting of a horizontal steel tank 8 ft.
ich the gas passes on its way to the fans. By
as a shut-off valve and by partly filling with
be reduced to any desired extent, these func-
a furnace is working badly and giving a poor
ft. tank also serves as a receptacle to which
ın the cooling sprays.

connecting the dust catchers to the fans is
the total travel of the gas from dust catcher
t. Located in this piping are 99 water sprays
s way to the fan washers. These spray noz-
xis of the pipe, about 3 ft. 6 in. apart, and dis-
pray into and against the flowing stream of
supplied from a 3-in. header through 1-in.
ıch spray consumes about 8 gal. of water per
s first into the 8-ft. tanks and from thence
cars beneath, where the dirt is deposited and
ı an overflow into the general drainage system.
to the fans are taken from the bottom of the
tion being 48 in. in diameter, enlarging to 70
ınection can be shut off from the gas pipe by
erated by a chain drum and handwheel located

y similar in general features to ordinary cen-
s. The wheels are 6 ft. 11 in. in diameter.
ı 15½ in. wide at the inner end and 13 in. wide
e-iron arms set in a cast-iron hub. The wheel
ıf steel plate is arranged for convenient access
wheel.
ːtion connections are rectangular. The main
ıranch 21 in. by 48 in. leads to each side of the
ː fan casing being 36 in. in diameter. These
ɜd with cleaning holes to facilitate removal
ːtions are provided for four nozzles on each
ː casing and discharging through the circular
e water from the furnace tuyeres and bosh
furnace troughs into a stand pipe equipped
ed at the proper level, and a portion of the
ɜ passes through pipes to the fans.
n by a 75-h.p. electric motor direct-connected
' a flexible coupling. Three of these motors
ːnt and the remaining motor is of the direct-
ıotors operate at about 500 r.p.m., the input
55 h.p. each. Control is by means of a
a small brick building just outside the fan

ges horizontally at the bottom through a 21½-
ı into a water separator. The separator is a
quare by 9 ft. high, containing a set of baffles
3-in. steel channels, the flanges of the channel
The openings between channels are about
ːeing is alternate or staggered, such that the
ːn and turned. The separated water and mud
the separator and passes out through a seal.
ːrator at the top through a 24-in. pipe connec-

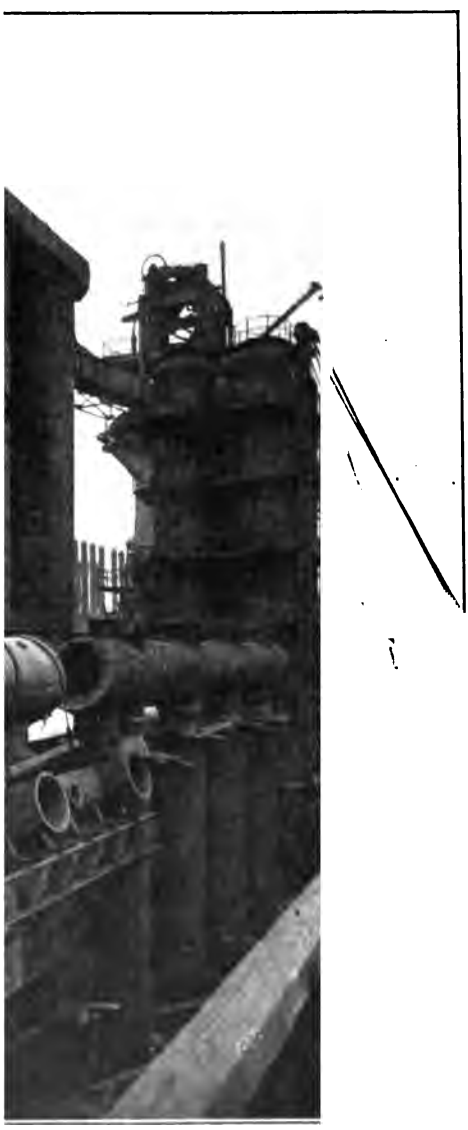
which has passed through one fan passes back
ːrtical connections on the cool gas main, and
ıeans of the disc valve at the top, previously
ıen flows through the second-wash fan to the
n; and thence through the 30-in. line to the

valves are so arranged that any fan may be
ːcond washing. The valves in the fan connec-

on top of the gas pipe. Each of these connections is provided with a hopper bottom, valve and drain, forming a pocket for the mud and water brought down with the gas. The drain pipe extends downward into a well, forming a seal.

FIG. 4 PIPING AT FURNACES 1 AND 2

20 The four fans are housed in a steel frame building enclosed with corrugated steel sides and roofing and open for light and ventilation on all sides.



ig. Towers at Furnaces 5 and 6

ed with water through three pipes rising
neter near the base of the tower. Each
. 1-in. connection provided with a plug

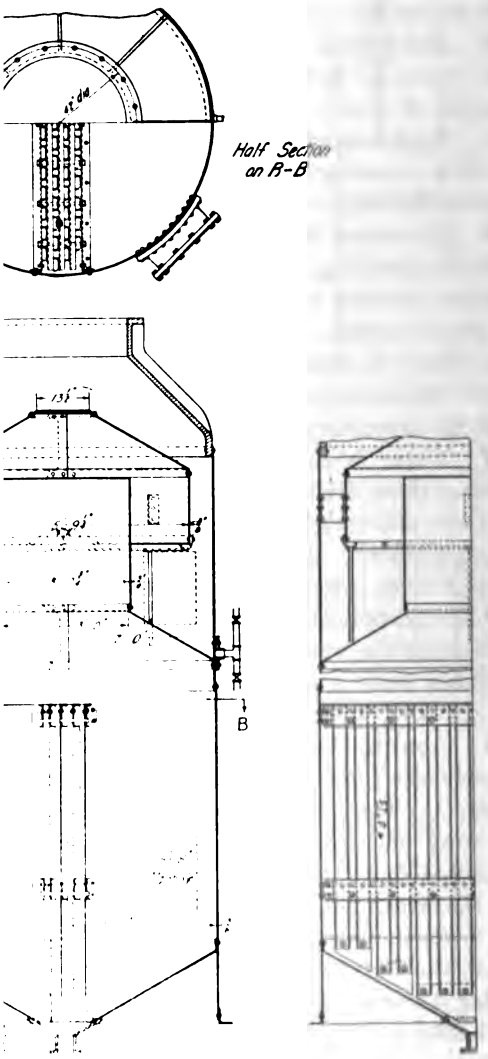
tions are 24-in. Chapman gates, with seats and discs of cast iron. The water valve and pipe main containing the cooling sprays are shown in Fig. 4.

GAS WASHERS NOS. 3 AND 4

27 The gas passes from the dry-dust catcher through a 96-in. connection leading to a set of four cooling towers 12 ft. in diameter and 72 ft. high. The cooling water is sprayed into these towers through numerous nozzles set in the sides. There is a set of towers for each furnace, the two sets being connected by means of an 84-in. header from the bottom of which the fans draw the gas for washing. The first-washed gas passes from the fans through a water separator into a 78-in. header called the first-wash main, from which it is passed back to the suction side of the fans working on second washing, these being shut off from the cooled-gas main. From these fans the gas passes through the separators and into the second-washed main of 60 in. diameter. The 60-in. main supplying the engines is connected to the middle point of this header.

28 The four cooling towers are carried on a structural platform about 30 ft. square and 18½ ft. above yard level. This elevation provides clearance for the mud cars placed beneath to receive the drainage from the bottom connections. The connections between the towers are 8 ft. in diameter and the travel of the gas is up and down in alternate towers. Each tower is provided with a hopper bottom and pipe seal having connection with a common drain pipe which delivers the discharge of all four towers to the tank cars beneath. Towers *A* and *B* are further provided with emergency seal drains at a higher level. These emergency seals are normally idle, but should the bottom drain become clogged the tower will then drain through the emergency seal. Tower *A* is further provided with a suspended steel plate baffle in front of the 96-in. inlet opening. This arrangement when filled with water to the required height acts as a valve to shut off communication between the towers and the dry-dust catcher, a sealed overflow maintaining the proper water level when desired. The first tower is equipped with about 30 sprays, the second has 35, and the third and fourth about 20 to 25 sprays each. The sprays are placed in five circumferential rows, 6 ft. apart vertically. The lower row is about 20 ft. from base of tower. These towers are like those shown in Fig. 5 for furnaces 5 and 6. Several of the illustrations are of the gas washing plant for furnaces 5 and 6, which are similar to that of furnaces 3 and 4.

nitor, the covering being of corrugated steel. inery are carried on pile and concrete founda-



ATOR FOR GAS WASHERS AT FURNACES 3 AND 4.

fan-shafts is 9 ft. 5 in. above yard level, this sary for drainage.

30 The standard nozzle, of brass throughout, is shown in Fig. 6. The shell has a $2\frac{1}{2}$-in. external pipe thread which screws into a flange riveted to the shell of the tower. The helical passage produces a whirling cone-shaped spray of about 90 deg., and 6 to 10 ft. diameter. The $1\frac{1}{2}$-in. plug provides convenient access to the spindle for cleaning. These sprays use about 7 gal. per min. at the average pressure carried.

31 From the towers the gas passes through a 7-ft. pipe to the fans. This pipe also is provided with nozzles which spray water into and against the approaching stream of gas, the nozzles being located at the center of pipe. The piping is well shown in Fig. 5.

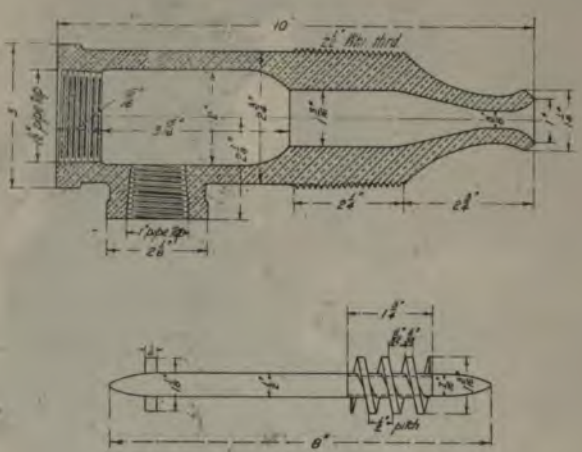


FIG. 6 DETAILS OF SPRAY NOZZLE

32 The gas leaves the cooled-gas main at the bottom and passes to the fans through vertical suction connections. The latter have hoppers and water-sealed drains at the lower end and may be shut off from the cooled-gas main by means of bell valves operated by a winch and handwheels located on top of the horizontal main. These valves seat in a water seal. The opening is of 45-in. diameter. At the midpoint of the cooled-gas main connecting the two sets of towers is located a shut-off valve consisting of an inverted siphon which may be partly or wholly filled with water to regulate the amount of gas coming from either furnace.

33 The fan washers are housed in a steel frame building 150 ft. long, 29 ft. wide and 32 ft. high from yard level to eaves, equipped

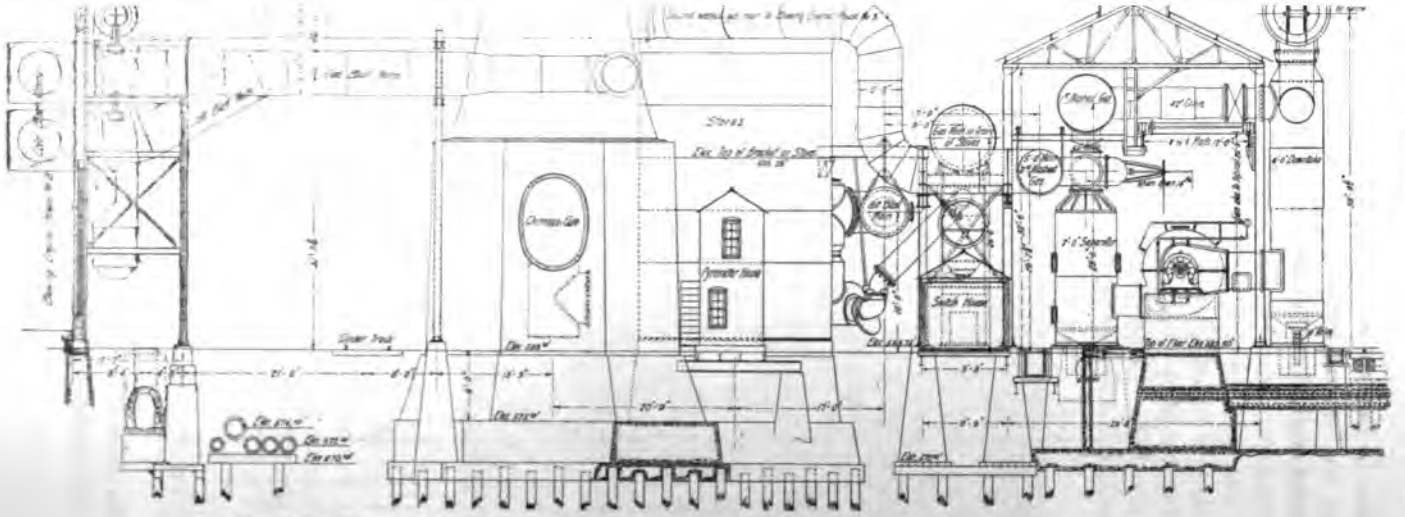


FIG. 8 GENERAL ARRANGEMENT ELEVATION OF GAS WASHERS FOR FURNACES 5 AND 6

34 There are eight centrifugal fans made by the Buffalo Forge Company. The wheels are of $\frac{1}{4}$-in. steel plate, 7 ft. 1 in. in diameter, having eight blades each $29\frac{1}{2}$ in. wide at the inner end, and $27\frac{1}{2}$ in. wide at the tip. Central opening of wheel is 40 in. in diameter.

35 The casing is of cast iron and of the double suction type. It is made in sections, with machined joints bolted together for removal of wheel. Manholes are provided for cleaning and inspection. Each branch of the suction connection is rectangular, 20 in. by 50 in., opening into the fan through a 36-in. diameter inlet. The bottom discharge connection is 40 in. by 36 in.

36 The wheel shaft, of $6\frac{1}{2}$-in. diameter, is direct-connected through a flexible coupling to a 100-h.p. motor operating at 480 r.p.m. Six of these motors utilize alternating current, the other two being for direct current. The two types are used so that should there be an accident to either circuit, the motors connected to the remaining circuit will continue to operate and keep a part of the engines running until the necessary corrections can be made.

37 Water is thrown into each fan through 16 spray nozzles. Eight of these discharge into the central inlet openings, four on each side; the other eight dischage into the fan through the upper half of its periphery. The sprays are fed by four $1\frac{1}{2}$-in. lines connected to a 6-in. header extending the full length of the building, over the fans. Each spray connection is a $\frac{3}{4}$-in. pipe. The water for the fan sprays is taken from the waste of bosh cooling water from the furnace, which overflows from a standpipe, a portion under the necessary head going to the fans.

38 From the fan the gas passes to a water separator constructed of steel plate 7 ft. in diameter by 13 ft. high. This separator is shown in Fig. 7. The gas passes first through a set of baffles consisting of four rows of 4-in. channels set vertically, the openings between the channels being $1\frac{1}{2}$-in. wide, with alternate or staggered spacing such that the streams of gas are broken and turned. The separated water falls down the vertical channels, carrying with it the dirt, and passes out at the bottom through a seal to the drainage system. After passing through the channel baffle, the gas rises through annular disc baffles and passes from the separator through a 36-in. top connection.

39 Each separator is equipped at the top with a cast-iron tee providing outlets through 36-in. gate valves respectively to first-washed and second-washed mains. Fans working on first washing discharge their gas into the first-washed main. This gas is then

ged that any fan may be operated on either

s are shown in sectional elevation in Fig. 8 and
-gas main and fan connections in perspective.
plant at furnaces 5 and 6 is substantially the
for furnaces 3 and 4. The water separators
baffling. These separators are shown in Fig.
iameter and 17 ft. high. The gas circulates
formed by narrow plates assembled as shown.

. 5 Gas Washer Fans and Piping

f plates are formed to catch the water and
the chamber, where it passes out through a
s of baffles through which the gas passes in
ttom and one at the top.

OWING-ENGINE HOUSES

ted the blowing engines are located in two
e houses Nos. 2 and 3, each substantially

taken by the fans working on second washing and by them discharged into the second-washed main. The diameters of the first- and second-washed mains are 78 in. and 60 in. The first-washed main

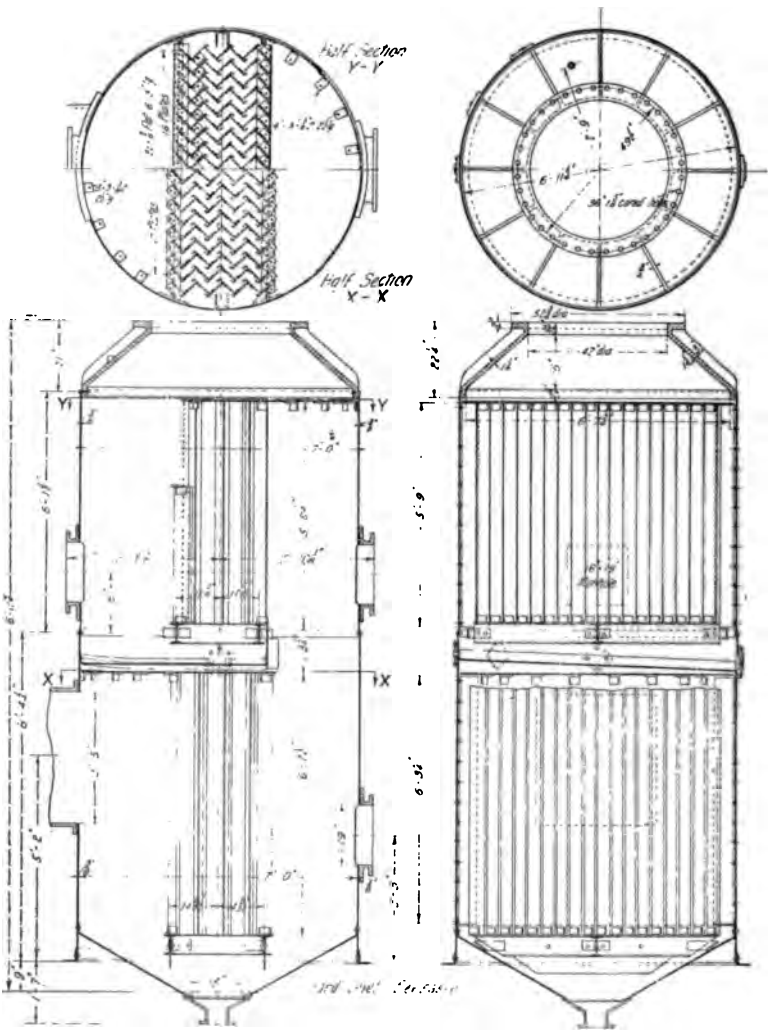


FIG. 9 WATER SEPARATOR FOR GAS WASHERS AT FURNACES 5 AND 6

extends full length of the fan house, and is connected to the vertical suction connection of each fan through a 42-in. gate valve. The valves

ıngement. Each blowing-engine house con-
ssing units (Fig. 13), each unit having a
00 cu. ft. of free air per min. when operating

built by the De La Vergne Machine Company
pled to vertical blowing engines built by the
ınd Machine Company of Philadelphia.
425 ft. long. A basement 10 ft. deep provides
system, etc. A steel skeleton frame supports
for a 35-ton electric traveling crane. The
l the roof of corrugated iron sheathed inside
:s through louvers located in the east wall at
The flooring is of ⅜-in. checkered steel plate
Two cold-blast mains, one for each furnace,
gth of building, and arrangements are such
engines can deliver to either of the two cold-
ping is so arranged that the north engine in
No. 2 can deliver to furnaces 1, 2, or 7. There
st main connecting blowing-engine houses Nos.
ıner that steam-driven blowing engines may
the seven furnaces, when required.
ses, jacket water, etc., are discharged into an
r header located about twelve or fifteen feet
ıd parallel to it. This tunnel is provided with
:he general drainage conduit, and the other to
:h a brick-lined steel stack located at mid-point
The exhaust tunnel is also provided with
posite each engine cylinder, and extending only
of the concrete foundation wall of the building.
/n in Fig. 12.
e of horse-shoe section of reinforced concrete,
The main tunnel is 10 ft. 2 in. high, 6 ft. wide
semicircular roof 8 ft. in diameter. The six-
8 ft. 2 in. high and 4 ft. wide.
; stack is 10 ft. in diameter of steel plate lined
. 2 in. diameter.
n the discharge chamber of each blowing cylin-
; main, is a non-return valve. The discharge
:cted to the atmosphere through a pipe extend-
ıg wall and controlled by a gate valve. This
n is opened when it is necessary to start with

ıngement. Each blowing-engine house con-
ssing units (Fig. 13), each unit having a
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for a 35-ton electric traveling crane. The
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ıd parallel to it. This tunnel is provided with
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The exhaust tunnel is also provided with
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of the concrete foundation wall of the building.
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semicircular roof 8 ft. in diameter. The six-
8 ft. 2 in. high and 4 ft. wide.
; stack is 10 ft. in diameter of steel plate lined
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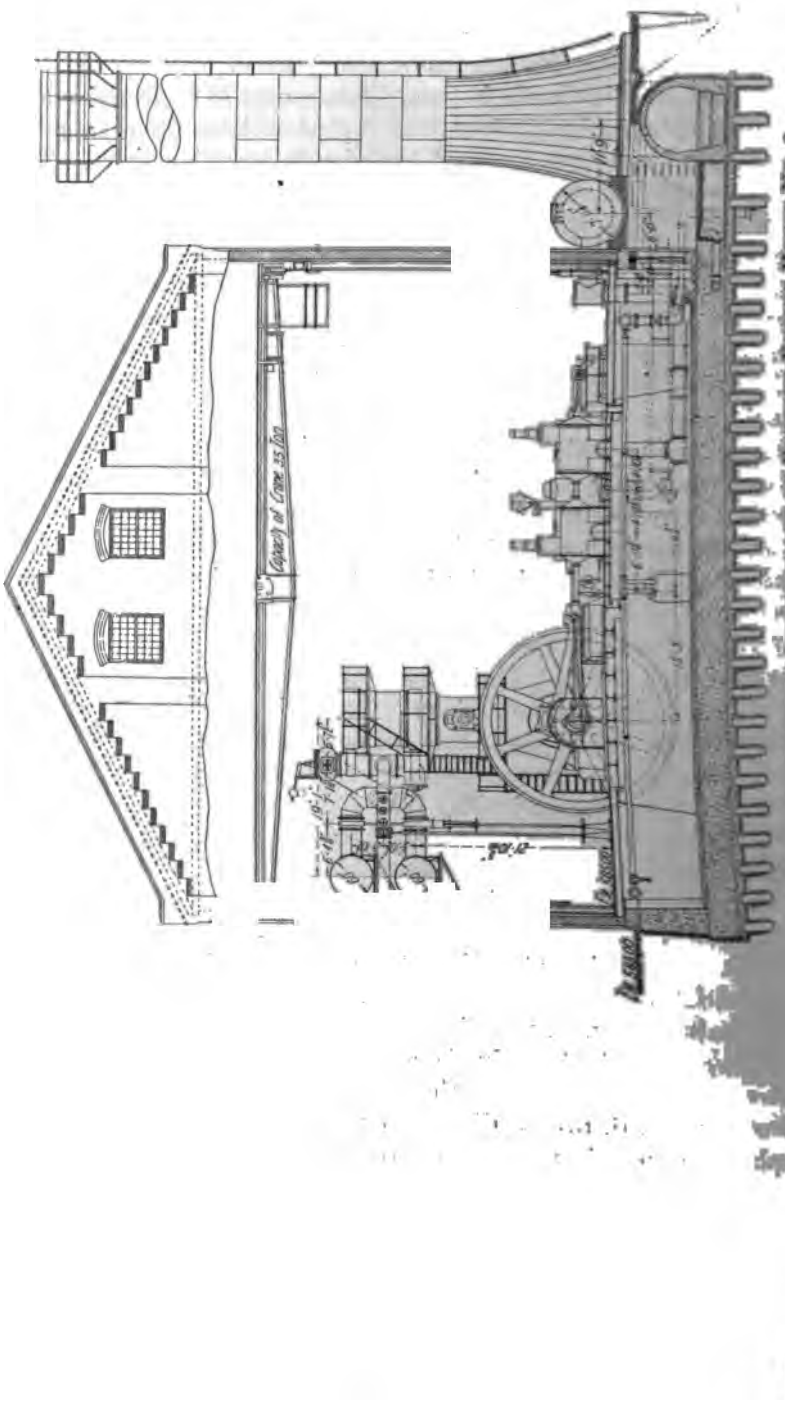
ıg wall and controlled by a gate valve. This
ı is opened when it is necessary to start with



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urns downward to the basement floor where it
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ıply from the basement through short connec-
. the floor.
xhaust pipe for each cylinder is 22 in. in diame-
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en extends horizontally to the east wall of the
lateral tunnel above noted. A tee outlet or
ırnished on the end of each exhaust pipe. A
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located just below the cylinder. This keeps
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ıter for the engines is taken from a 12-in. main
gth of the building on the east side of the base-
ve main is installed on the west side. Opposite
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The system has since been modified such that
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muffling sprays.
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nd cylinder jackets. The jacket water leaving
discharges upward through a vertical pipe pro-
-bend discharge nozzle. The water leaving the
ıwnward into a funnel leading to the cylinder
hus being in full view of the operator.
ir for starting is supplied through a 5-in. branch
delivering air from power house No. 1. The
ides into two 3½-in. branches, one to each side
it connects with the starting valve.

compressed air. When operating conditions have been established in the motor cylinders, the gate valve is closed and the non-return valve rises from its seat for delivery into the blast main.

49 Gas is delivered to each engine from the main header located outside the building through a 24-in. branch, including a standard 24-in. gate valve just inside the building wall and above floor level. The 24-in. pipe then turns downward to the basement floor where it divides into two 18-in. branches, one to each gas pump. The air pumps draw their supply from the basement through short connections passing through the floor.

50 The cast-iron exhaust pipe for each cylinder is 22 in. in diameter. It is attached to the bottom of the cylinder, descends vertically about six feet and then extends horizontally to the east wall of the building and into the lateral tunnel above noted. A tee outlet or double discharge is furnished on the end of each exhaust pipe. A gate valve is provided.

51 During operation water is injected into each exhaust pipe through spray pipes located just below the cylinder. This keeps the pipe cool, partially muffles the exhaust, and prevents explosions in the exhaust piping.

52 The cooling water for the engines is taken from a 12-in. main extending the full length of the building on the east side of the basement. A 10-in. reserve main is installed on the west side. Opposite each engine is located an 8-in. connection with valve. From this connection a 6-in. branch leads to each side of the engine. The supply of water for each engine is thus controlled by one valve.

53 As originally installed, cylinders, pistons and muffling sprays were all supplied with water through individual connections, each wasting to a sewer. The system has since been modified such that the water passes through piston, cylinder heads, cylinder jackets and muffling sprays in the order named. A small portion of the water only is used by the muffling sprays.

54 Thermometers are placed to indicate the temperatures of water leaving the piston and cylinder jackets. The jacket water leaving each cylinder head discharges upward through a vertical pipe provided with a return-bend discharge nozzle. The water leaving the nozzle discharges downward into a funnel leading to the cylinder jacket, the stream thus being in full view of the operator.

55 Compressed air for starting is supplied through a 5-in. branch from a 6-in. main delivering air from power house No. 1. The 5 in. connection divides into two $3\frac{1}{2}$-in. branches, one to each side of the engine where it connects with the starting valve.

OILING SYSTEM

56 An oiling system of the gravity type is installed at each blowing-engine house. Two 500-gal. storage tanks are located near the roof from which the oil is piped to the sight-feed connections on the engines. A complete system of drip pans and oil catchers is provided at the engines. From the pans the oil drains to the basement, and passes first through a gravity separating tank where most of the water is removed. The oil then flows over a heating device where its temperature is raised to about 120 deg. fahr. and it then passes through settling tanks and weir boxes, where the remaining water and nearly all of the suspended matter are deposited under the action of gravity. From the weir boxes the oil passes into White Star filters, and thence by means of a duplex steam pump to the storage tanks located near the roof.

57 The above description applies to the system used for supplying oil to parts of the engine where the oil is but slightly contaminated by foreign matter. At certain other points of lubrication, such as the gas pump and motor piston rods, etc., the return oil is contaminated to a considerable degree by flue dirt. A separate system very similar in principal to the one already described is installed to take care of these parts.

58 The buildings are heated by means of the forced circulation of hot water through radiation piping. The piping extends entirely around the building and the water which is heated by exhaust steam, is circulated by means of a centrifugal pump.

POWER HOUSE

59 Eight units for developing electric power, each rated at 1000 i.h.p., are located at the south end of power house No. 1 and occupy a space 350 ft. long. The engines are direct connected to 500-kw. generators, four of direct current, 250 volts, and four of three-phase 25-cycle alternating current, 440 volts. The total length of the building is 725 ft., the width 77 ft. and the height from the floor line to the bottom chord of the roof truss 35 ft. A steel skeleton frame supports the roof and crane runways. A basement 8 ft. deep is provided and a concrete matte, on piling 83 ft. wide by 4½ ft. thick, supports the building and machinery. An interior view of the power house is shown in Fig. 14.

ncrete reinforced with expanded metal, resting
ı gratings between the engines ventilate the

d is placed on a platform 213 ft. long at the
ng. A controlling panel is provided for each
nerous feeder panels control the various mill
ing-current switches are located at the south
l the direct-current control at the north end.
haust into the main drainage tunnel and a
ameter and 60 ft. high carries away the gases

ıkes gas from a 30-in. main outside the west
ırough an 18-in. connection controlled by a gate
ıection divides into two branches, one going to
hrottle valve controlled by a Tolle governor
s possible to the valve chest of its respective
in each of these branches.
draws its supply from the basement. Com-
ıg is provided through a 6-in. main extending
e plant. There is a 4-in. branch at each engine.
ıter is supplied from the general yard service
with branches at each engine.
linder is provided with a separate exhaust pipe
hausting directly into the tunnel. Water is
to cool and muffle the exhaust.

NG TWO-STROKE CYCLE ENGINES

ere designed by the firm of Koerting Brothers,
ınd were built by the De La Vergne Machine
c. They are of the two-stroke cycle double-
type.
ıgine units have motor cylinders 38½ in. in
troke, and occupy a floor space of 40 ft. by
or electric generating have cylinders 24¾ in.
n. stroke and occupy a floor space of 32 ft.

peration with reference to the motor cylinder
ıd air are compressed in separate pump cylin-
bout 10 lb. per sq. in. above atmosphere. The
ıe mixing chamber above the inlet valve of the

OILING SYSTEM

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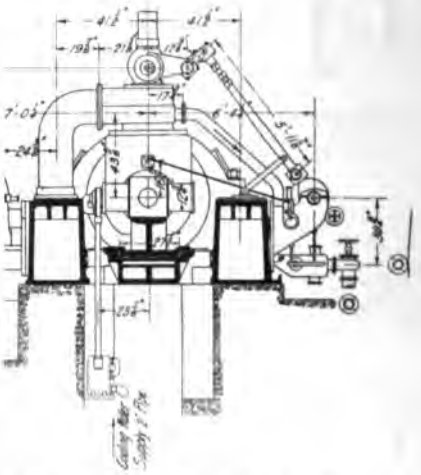
57 The above description applies to the system used for supplying oil to parts of the engine where the oil is but slightly contaminated by foreign matter. At certain other points of lubrication. such as the gas pump and motor piston rods, etc., the return oil is contaminated to a considerable degree by flue dirt. A separate system very similar in principal to the one already described is installed to take care of these parts.

58 The buildings are heated by means of the forced circulation of hot water through radiation piping. The piping extends entirely around the building and the water which is heated by exhaust steam, is circulated by means of a centrifugal pump.

POWER HOUSE

59 Eight units for developing electric power, each rated at 1000 i.h.p., are located at the south end of power house No. 1 and occupy a space 350 ft. long. The engines are direct connected to 500-kw. generators, four of direct current, 250 volts, and four of three-phase 25-cycle alternating current, 440 volts. The total length of the building is 725 ft., the width 77 ft. and the height from the floor line to the bottom chord of the roof truss 35 ft. A steel skeleton frame supports the roof and crane runways. A basement 8 ft. deep is provided and a concrete matte, on piling 83 ft. wide by 4½ ft. thick, supports the building and machinery. An interior view of the power house is shown in Fig. 14.

ng the period when the motor piston is at and
ts stroke, the inlet valve opens, admitting first
d second the mixture to the motor cylinder.
ke of the piston the charge is compressed to a
ıt 150 lb. gage.
ctric spark takes place somewhat prior to the
ıpression stroke. Near the end of the expan-
on uncovers the exhaust ports through the
pening of the inlet valve occurs very soon there-
ıcoming charge forces the burned gases out
orts, completing the cycle.
an and elevation of the 2000-h.p. engine is
awings in Fig. 15*a* and Fig. 15*b*. The smaller
ar in general design.



END ELEVATION OF 2000-H.P. ENGINE

mposed of two separate engines, each complete
ption that the crankshaft is common to both.
e for each side is composed of two heavy cast-
e motor cylinder is supported on and between
ne shaft bearings are formed in the other end

e the gas and air-pump cylinders. The two
on a single piston rod and driven by an over-
ıter end of the crankshaft.

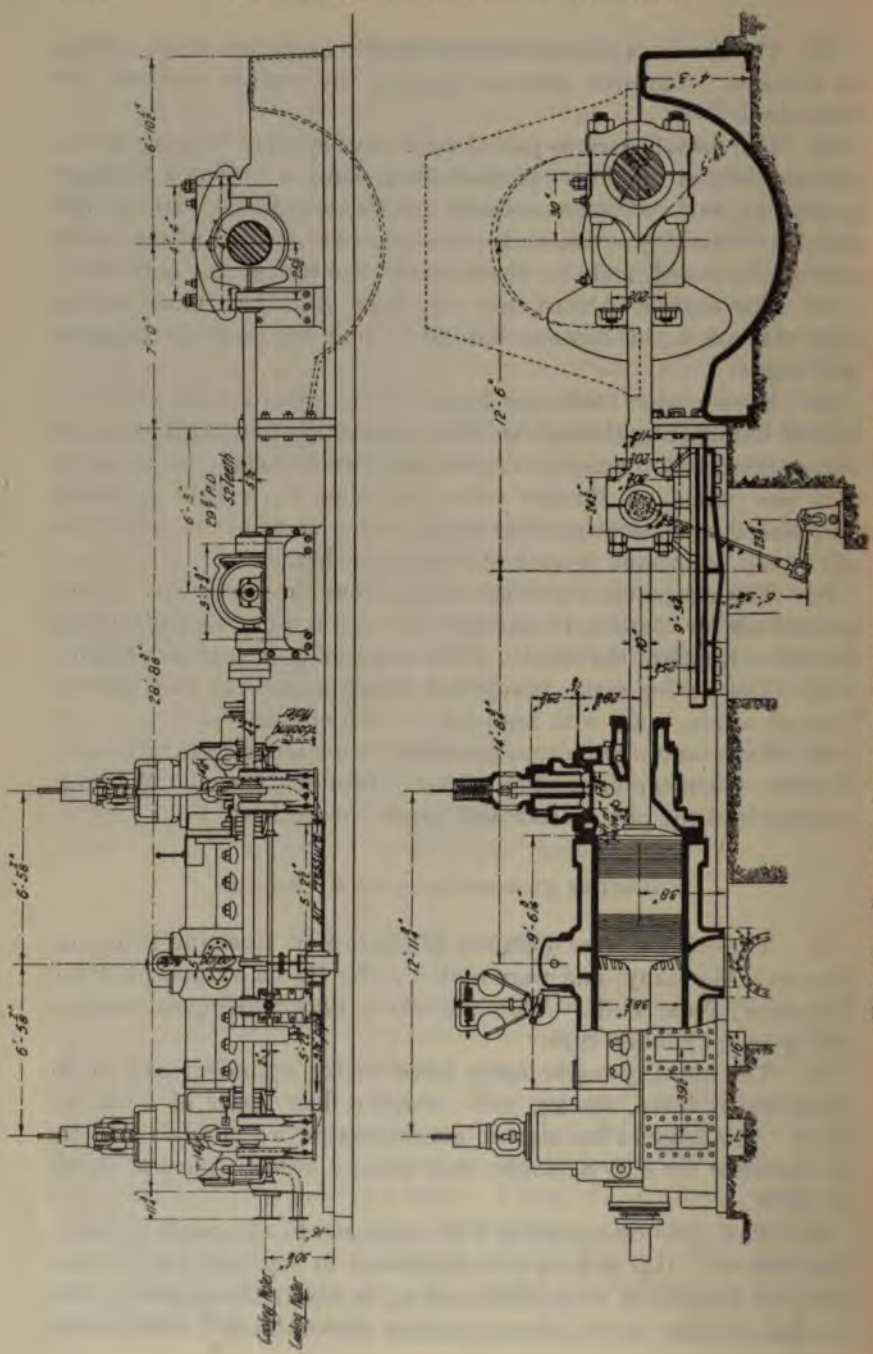


FIG. 15a GENERAL ASSEMBLY ELEVATION OF 2000-H. P. ENGINES

FIG. 17 DETAILS OF MOTOR CYLINDER

FIG. 16 DETAILS OF CYLINDER HEADS AND INLET PORTS

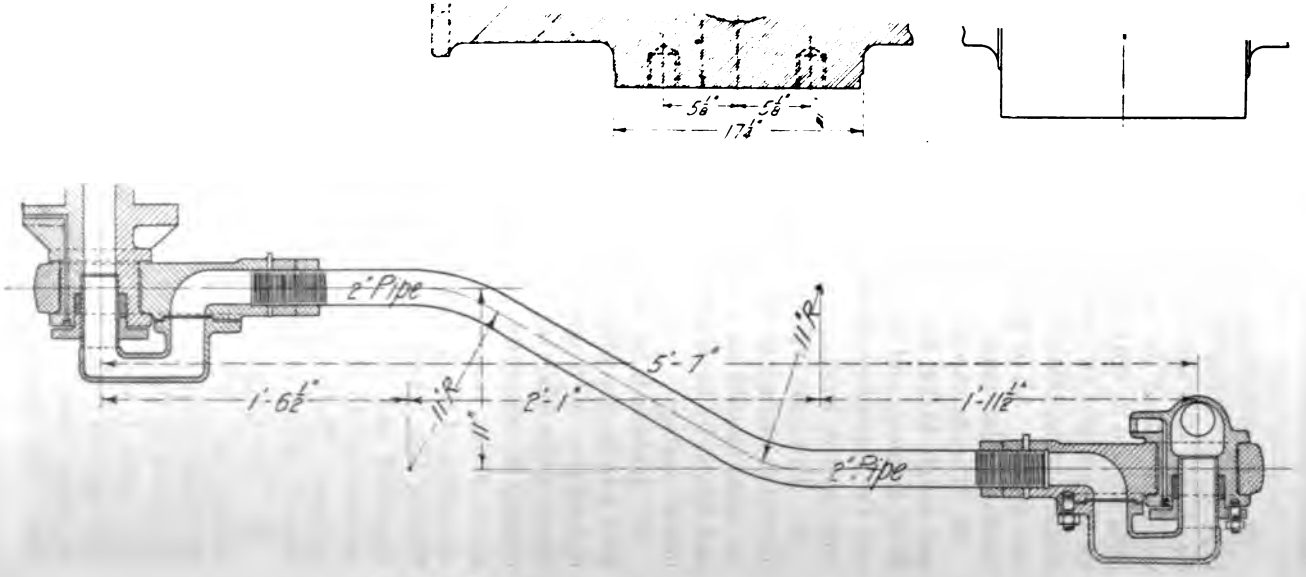


FIG. 19 DETAILS OF WATER CONNECTION FOR PISTON ROD

75 The pump valves are of the piston type, smooth cylinders without packing of any kind, and are driven by eccentrics on the crankshaft. The induction valve for the gas pump is open during about 145 per cent of its suction stroke; that is to say, during the entire suction stroke as well as the first 45 per cent of the discharge stroke. The air pump discharges during nearly its entire stroke, the object being to provide scavenging air for the motor cylinder prior to the entrance of the mixture. The gas and air pass from their respective pumps through ducts to a mixing chamber above the motor inlet valve. The prior discharge action of the air is intended to force the gas column back into its duct, prior to the opening of the motor inlets, in such manner that scavenging air is provided in advance of the mixture.

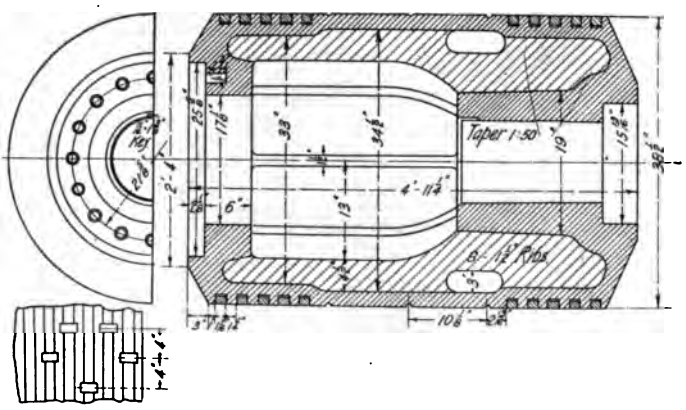


FIG. 18 DETAILS OF MOTOR PISTON

76 The motor cylinders are of cast iron in one piece with water jacket and exhaust passage. The cylinder heads (Fig. 16) are of cast iron with water jackets and are provided with an expansion joint. Fig. 17 shows a 38½-in. motor cylinder in detail.

77 The piston is of cast iron, nearly as long as the stroke because of its action as an exhaust valve. Five grooves are provided at each end, equipped with dowells in such manner that the five snap rings are held with their openings near the bottom of the cylinder. The piston (Fig. 18) resting on the cylinder wall closes the opening through the ring and prevents leakage and possibly premature ignitions. Cooling water is supplied through the hollow rod by means of swinging connections shown in Fig. 19.

78 The crosshead is of the slipper type babbitt faced. The marine type connecting rods are forked at the crosshead end. Bear-

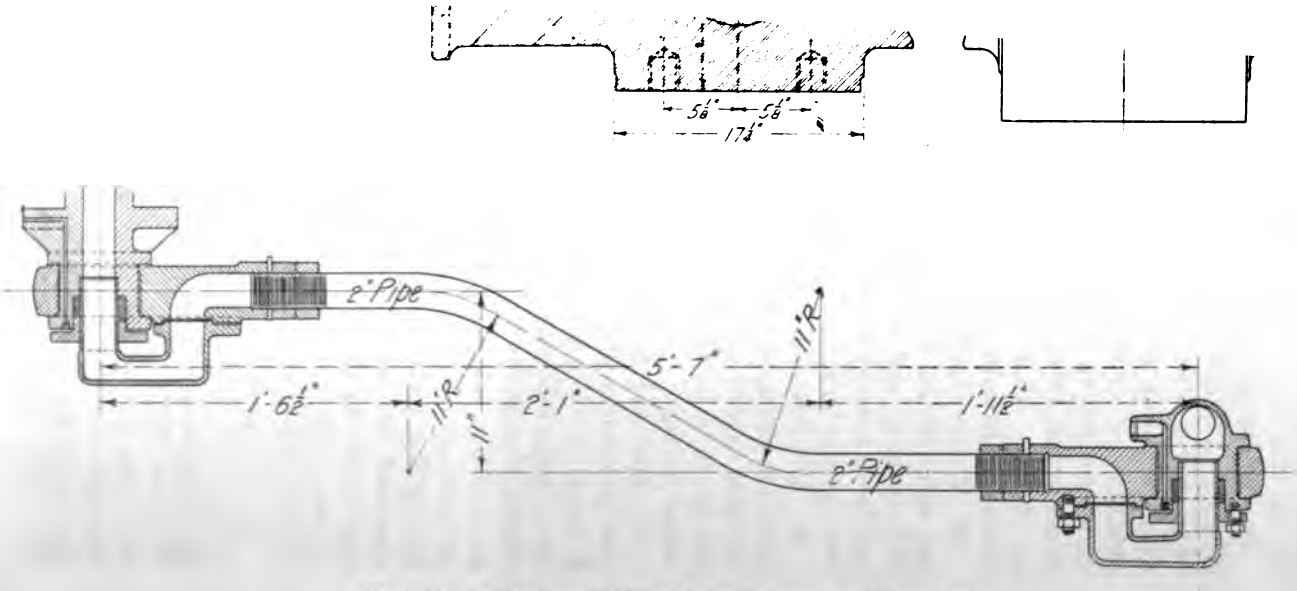


FIG. 19 DETAILS OF WATER CONNECTION FOR PISTON ROD

ings are split shells, babbitt lined for the crank and phosphor bronze for the crossheads, held by bolted caps.

79 The crankshaft for the 2000-h.p. engine is of the built-up type and is carried by four bearings. Each crank pin is carried by two forged steel webs between its pair of main bearings and to these webs are bolted the counterweights. Each end of the shaft projects beyond its outboard bearing and carries a crank and eccentrics for the gas and air pumps. The shaft for the 1000-h.p. engine is a single forging, being in other respects similar to that for the 2000-h.p. engine. All of the principal forgings were made at the Krupp works in Germany.

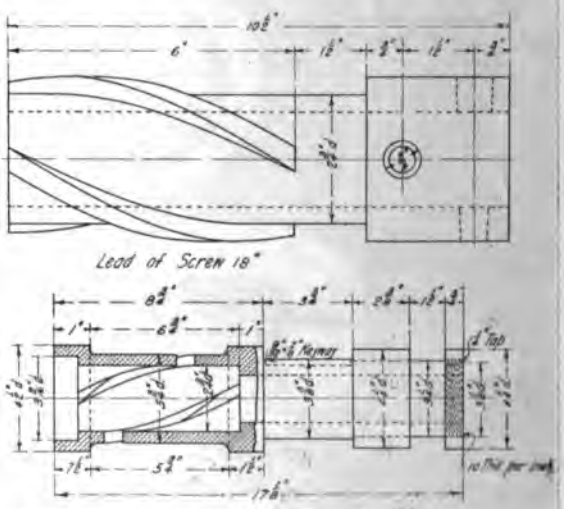
80 The flywheels for the 1000 h.p. engines are 17½ ft. in diameter and weigh 45,000 lb. The wheels for the 2000-h.p. engine are of 20 ft. diameter and weigh 65,000 lb. The wheels were cast in halves, and the fastenings are steel links shrunk into place at the rim and bolts at the hub.

81 The inlet valves are steel forgings of the mushroom type located in casings at the top of the cylinder heads. They are opened by cams located on a shaft parallel to the axis of the motor cylinder and driven by bevel gears from the crank shaft, and closed by strong helical springs.

82 Ignition is by means of electric spark of the break or arc type, with two igniter plugs in each cylinder head. The electric current is furnished by magnetos, one for each plug. The current is produced in the following manner: The magneto armature is first slowly rotated in opposition to the force of a spring through an angle of about 30 deg. from its initial position. It is then released and under the action of the spring executes a rapid return motion or oscillation. During this return motion the igniter terminals are mechanically separated and the arc formed, the motion of the armature being transmitted to the plugs through cranks and reach rods for this purpose. The magnetos are now being discarded in favor of a direct-current system of ignition of simple form.

83 The timing of the ignition is accomplished by means of the igniter shaft connected to the cam shaft through a helically slotted sleeve and a pair of spur gears. By sliding the sleeve along the shaft, the phase of the igniter shaft is advanced or retarded. One of the spur gears is provided with sufficient width of face to accomplish the required range of movement. The sleeve and hub form a triple threaded screw and nut, and have proved very satisfactory in operation. The apparatus is shown in Fig. 20. The equivalent device

ers consisted of a single spiral slot and feather
ve in wearing qualities.
of the 1000-h.p. units is by a butterfly throttle
rol of a Tolle governor. The strength of these
2000 lb. The throttle valve is located in
of each pump, as close as possible to the pump.
engines are regulated by means of bypass
gas pumps, and under the direct control of an
pressure governor. Each gas pump, in addition



SCREW AND NUT FOR IGNITER SHAFT

ibuting valve, is provided with a reciprocating
from the pump valve-gear. This valve is of the
ned to a working fit in its valve cylinder bush-
with ports through the walls of the hollow plug.
through the walls of the valve cylinder bushing
tively with A, the gas pump discharge passage,
p clearance. Two respective leakage paths are
h which a portion of the gas is bypassed back
of the gas pump. The hollow plug valve of the
for partial rotation on its axis under control of
he angular position of the plug valve determines
g of the bypass ports, which in turn governs the
ned to the pump supply pipe. Due to the con-

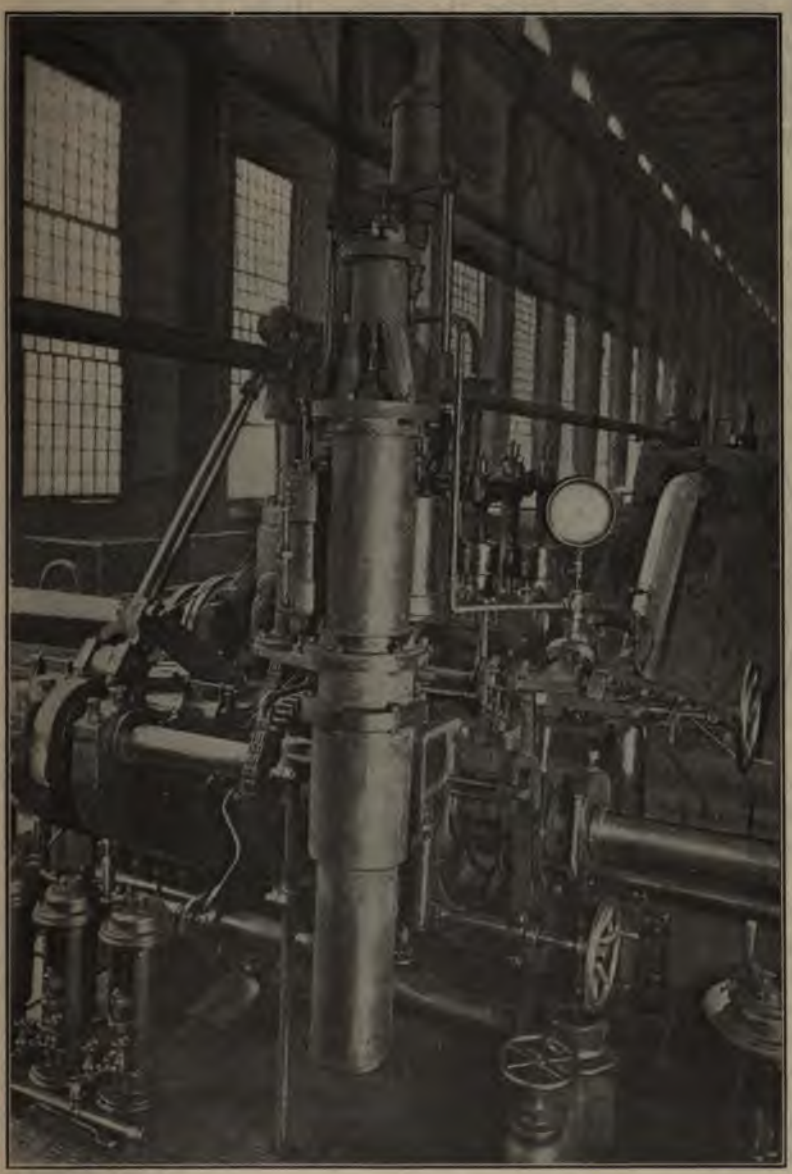


FIG. 22 GENERAL VIEW OF OIL-PRESSURE GOVERNOR

struction of the main pump valve, bypassing from the passage *A* can occur only during the suction stroke of the pump, the bypass port being connected to a chamber which communicates with the pump discharge passage only during such suction stroke. The bypass port from the pump clearance allows bypassing to occur during the discharge stroke of the pump.

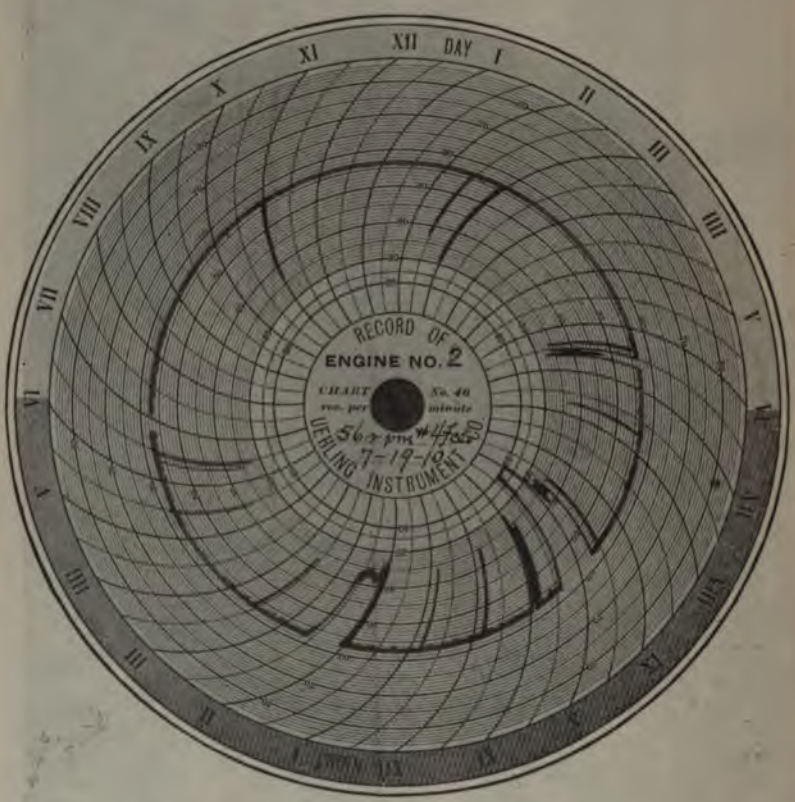


FIG. 23 SPEED CHART—REVOLUTION RECORDER

86 When the governor is in the position corresponding to maximum power demand, both bypass ports are closed. As the demand for power decreases, the port from passage *A* is first opened, the port *B* remaining closed. With a further decrease of power demand port *B* also opens. The port *A* is arranged for prior opening for the purpose of removing the gas from the vicinity of the motor inlet at and

ıg period. The full opening of both bypass imit the engine speed to about 45 r.p.m. under load. The reciprocating motion of the valve ɔurpose of preventing accumulation of dirt on ıus preventing any undue resistance to rotation :he governor. The general arrangement of the ɜ shown in Fig. 21.

is of the adjustable-speed oil-pressure type, es directly by means of a piston of $4\frac{1}{16}$ in. in differentially against the force of a spring. The e spring is about 830 lb. A $3\frac{3}{4}$-in. by 3-in. oil pump is driven by means of a 2-in. Renold ɜ cam shaft of the engine. The oil is discharged ɜe of special design, the area of which is controlled The motion of the small piston is transmitted and reach rods, and controls the angular position The needle valve is linked to the timing device anism in such manner that the time element or ɜ neutralized, the ignition remaining constant at

ariation between the extremes of travel is 4 per required to drive the pump amounts to about ɜ gear, governor, and timing device were designed the assistance of Mr. Hugh Boyd and the entire ɜtructed in the shops of the steel company.

arrangement of the governor is shown in Fig. 22 he Uehling revolution recorder in Fig. 23. The ecorded in the latter indicate periods of casting furnace.

rication of the motor cylinders is accomplished ɜ of the screw-press plunger type. These pumps ɜ and ratchet, operated by cams located on the The oil pump cams are located in such manner on occurs during each compression stroke of the ɜre are three oil inlets for each end of the motor ɜ top and one at each side near the bottom. An ınger serves each oil inlet, which is provided with

KOERTING ENGINES

Item	Electric Power	Blowing Engine
Rated h.p.	1000	2000
Speed, r.p.m.	100	35 to 65
Diameter, motor cylinder	23¾	38½
Stroke, motor cylinder	43¾	60
Diameter, gas pump	28¾	45½
Diameter, air pump	25¾	38½
Stroke of pumps	33½	49½
Main journals	Four 12¾ × 23¾	Two 18 × 33 One 22 × 40 One 22 × 35
Maximum shaft diameter	18½	26
Length of shaft	26 ft. 6 in.	34 ft. 7½ in.
Crank pins	Two 12¾ × 13¾	One 24 × 16 One 18 × 19½
Crosshead pins	Four 8½ × 7¾	Four 12¾ × 11½
Piston rod	6 5/16	10
Crosshead shoe	19¾ × 36¼	27½ × 52
Connecting rod	9 ft. ¼ in.	12 ft. 6 in.
Diameter, connecting rod		
Large end	8 11/16	12½
Small end	7½	10
Pump piston rod, diameter	4	5½
Pump crank pin	4 5/16 × 5½	6¼ × 8
Cam shaft, diameter	3½	4¾
Motor inlet valve, diameter	12¾	18¾
Gas pump inlet valve, diameter	13	18
Air pump inlet valve, diameter	12	18
Exhaust pipe, diameter	15¾	22
Flywheel, diameter	17 ft. 6 in.	20 ft.
Flywheel weight	45,000	65,000
Blowing cylinder, diameter	—	76
Blowing-engine, stroke	—	60

GENERAL NOTES RELATING TO OPERATION

91 Both gas-cleaning apparatus and the gas engines were installed at an early stage in the history of the art and are necessarily imperfect when compared with modern examples to which have been applied those essential refinements that can be gained only through experience. The average dust content of gas as delivered to the second-washed main amounts to about 50 to 80 mg. per cu.m., equivalent to from 0.022 to 0.035 grains per cu. ft.. which would rightly be

tice in modern gas-cleaning plants. It therefore
e type of engine selected is able to operate per-
plied with this imperfectly cleaned gas, without
er.

, operation of the character named cannot be
three years. The author believes, however, that
ıe trouble can be traced to several major causes
premature combustion and a number of minor
ıpreciated at that time.

ons tending to produce premature combustion
ıre of parts subject to the resulting high pressures
vere: imperfect piston packing which was neither
nor provided with keepers; unsuitable oil used in
's; and high hydrogen content in the gas. Minor
re combustion were: projecting portions of parts
; and accumulations of flue dirt which, in combina-
baked on the surfaces of the parts; the projecting
incandescent and initiating premature combustion.
re also due to various causes, such as wet gas which
points with its accompanying flue dirt; dirty gas
e valves of the controlling devices, making the
e difficult; imperfect rod packing, etc., which pro-
pheric conditions in the building; inadequacy of
e 1000-h.p. engines subject to high inertia stresses

r dowells are now applied to the piston grooves
ıner that the openings through the snap rings are
ion near the bottom of the cylinder, thus preventing
he openings. The cylinder oil now used does not
ous residue of any considerable magnitude. The
supply to tuyeres, coolers, and bosh plates is
y lower than the internal pressure of the furnace;
t enter the furnace to produce excessive hydrogen,
of these parts.

ıS-CLEANING AND SUPPLY SYSTEM

ly noted, there are three gas-cleaning plants, one
naces; and the three delivery mains therefrom are
means of pressure-equalizing pipes, two in number.
ıt gas, cooled gas, and washed gas are locally inter-

connected in parallel relation at each pair of furnaces. It possible to control the amount of gas taken from each furnace and the gases from the two furnaces are thoroughly mixed by discharging into a common washed-gas delivery main. In order to promote in the best manner uniformity in the constitution of the gas, the delivery from the several washeries should then discharge into a common distributing main or holder. Referring to Fig. 1, however, it will be noted that the locations of the three delivery mains, and the relative locations of the two equalizing pipes are such that it is impossible for such mixing to occur even locally or approximately. A partial solution constituting a great improvement would consist in relocating the 30-in. delivery pipe from washers Nos. 1 and 2 along the west wall of blowing-engine house No. 2, to form a junction at the southwest corner of that building with the 60-in. delivery main from washers Nos. 3 and 4. Also the 36-in. equalizing main should deliver gas into the 60-in. delivery main from washers Nos. 5 and 6, instead of into the north end of the 96-in. header at blowing-engine house No. 3. Power house No. 1 and blowing-engine house No. 2 would then receive the average of gas from four furnaces, whereas at present blowing-engine house No. 2 receives gas only from furnaces 3 and 4, and at power house No. 1, the four north engines may receive gas from furnaces 1 and 2, and the four south engines from furnaces 3 and 4. Under these conditions of piping, the gas supply at any point is but an average of that from two furnaces, and at times the irregularity is considerable, the thermal value occasionally varying between limits of 105 and 80 B.t.u. per cu. ft., within a period of a few seconds.

96 Owing to the fact that hot gas mains of the three pairs of furnaces are not interconnected, the danger of explosion due to the entrance of air is enhanced to a certain degree, especially when but one furnace of any pair is in operation. This danger is minimized to some extent by means of the equalizing connections between the several washed-gas delivery mains, and the remaining conditions are provided for through the skill and watchfulness of the operators, who are greatly assisted in their work by a system of local telephones, and by indicating and recording vacuum and pressure gages connected at the proper points. Such conditions, however, occur only during checks and casts at the furnace, or in case of failure of the cooling-water supply. Such periods are easily taken care of by the operators, who thoroughly appreciate the situation. The principal precaution consists in sealing off the connection between towers and dust catcher, before the wind

:e, one furnace of the pair being assumed already
ans are also shut down or bypassed, and the fan
f when necessary, there being a diaphragm seal
:ction of each fan washer. The most probable
air into the system is through the furnace top and

are provided at each washer as follows: There
re gage for the second-washed main, a recording
: gage for the cooled-gas main, and a manometer
), Fig. 3.
ates on the domes, and on the walls near the
l *B*, especially during the winter months. The
nulations, if not otherwise known, is announced
f overflow water at the emergency seal, due to
rmal outlet for dirt and water at the bottom of
:umulation at the bottom is then broken up by
ıgh the gate valves and pipe tees provided at the
tion of each tower for that purpose. This occurs
e a month and occasionally twice a day. These
rgely due to the fact that there is not sufficient
ater to the upper three rows of nozzles, which are
e; the dome and upper walls are therefore not
ater, and the dirt accumulates. The accumula-
an washers and their connections is practically
:er separators require cleaning once and occas-
The type of separator shown in Fig. 10 collects
han the other form. Contemplated improve-
y for obviating these difficulties.
ıe furnace top at a temperature of about 550
ıer it enters the fans at about 77 deg. and leaves
)0 deg. fahr. The water used in the tower
5 gal. per 1000 cu. ft. of gas. The quantity of
the fan washers is not accurately known.
there are eight nozzles which discharge water
the upper periphery, and four nozzles which dis-
inlet openings of the fan. The quantity of water
:ially at the gas inlet, greatly affects the power
n, which increases with the amount of water used.
Nos. 1 and 2 requires about 45 h.p., while about
each fan at washers Nos. 3 to 6. The operation
the fan washers is required under present load

conditions. Hence, allowing for losses in motors, about five per cent of the delivered horsepower at the engines is required for driving the fan washers.

101 The cleaning of the gas at washers Nos. 1 and 2 is less complete than that at washers Nos. 3 to 6. At the two former the dust content in second-washed gas as delivered averages about 0.035 grains per cu. ft.

102 At gas washers Nos. 3 and 4 the dust content in the gas is about as follows:

Gas	Cooled	First-Washed	Second-Washed
Average grains per cu. ft	0.328	0.061	0.022
Maximum grains per cu. ft	0.980	0.100	0.100
Minimum grains per cu. ft	0.0044	0.0044	0.0044

103 The gas supplied through the 30-in. main to power house No. 1, therefore, contains more dirt and moisture than that delivered from washers Nos. 3 to 6, in consequence of which there is more trouble with dirt at the power house than at the blowing-engine houses. Also it may be noted that the long 8-ft. gas headers at the blowing-engine houses are of probable value in separating the moisture from the gas.

LUBRICATION

104 As previously noted, each motor cylinder is supplied with cylinder oil by six pumps of the screw plunger type. The pumps are arranged in two batteries, one for each end of the cylinder, each comprising three plungers driven by a combination cam, lever, ratchet, and worm gearing, common to the three plungers of the battery. During each compression stroke of the motor piston the three oil pump plungers are depressed through a small distance into the oil pump cylinders. In this way three small equal quantities of oil are forced into the end of the motor cylinder during the corresponding compression stroke of the motor piston, one quantity entering at the top and the others on either side near the bottom of the motor cylinder, at points about midway between the cylinder head and the exhaust ports. The oil pump discharge connections are filled with oil in order to exclude any possibility of the presence of air. The resulting lubrication is thorough, effective and satisfactory. The oil used is known under the trade name of Electric Gas Engine Oil. The flash test is about 450 deg. fahr. and the oil fires at about 550 deg. fahr. The author believes that the long piston of the two-stroke cycle engine is especially conducive to satisfactory cylinder lubrication. The cylin-

blowing engine amounts to about 5.25 gal.

own under the trade name of Dynamo Oil is sup-
y points by means of an oil purification and dis-
eady described. This oil circulates again and
earings, and each day a sufficient quantity of fil-
m the system and used for lubricating the piston
d air pump cylinders. The quantity of engine
ving engine, including oil actually consumed by
p cylinders and motor piston rods, plus the daily
ge, evaporation, etc., in the purification plant,
3.7 gal. in 24 hours.

to the above there is required for the blowing
al. of air-cylinder oil, and for small pin bearings,
of No. 2 cup grease per 24 hours. The delivered
blowing engine varies from 1000 to 1200.

ipes for delivering oil to the motor cylinder are
the walls of the cylinder, and project radially
acket, passing out through stuffing boxes in the
eel pipe formerly used corroded rapidly, allowing
er the motor cylinder during operation. The
pipe eliminated this trouble.

l that dirt accumulated in the two nipples where
otor cylinders at each end near the bottom of
adually baked with the oil, plugging the connec-
consisting of a pipe tee and cock was provided,
settled to be blown out at leisure.

IGNITION

construction of the igniter plugs is indicated in
bushing forming the spherical seat for the mov-
is a driving fit in the cast-iron body of the plug.
of the stationary electrode seats on an asbestos
rried by the porcelain insulating plug which is
frustrum seated in a cavity in the cast-iron plug
rge and glycerine. Litharge also assists in main-
ween the cast-iron plug and the bronze bushing.
very satisfactory in every way.

to or similar low-voltage current, there is little
ls, and the life of both electrodes is about one

year. The bronze bushing lasts about six months, this material being the most satisfactory thus far used. The upkeep of the magnetos is relatively expensive, and a ten-volt direct-current system is being substituted.

111 Dirty plugs are caused by slipping furnaces and wet gas containing dirt which fouls and bakes at the terminals. The plugs require cleaning on an average of once to twice per month. The spherical seat requires regrinding once in two months, and the plug must be retubed one in six months.

112 Premature combustion is due to high hydrogen content in the gas, sharp edges or corners of metal exposed to the flame, dirt, and improper piston packing. Back-fires are due to prematures during the period of inlet opening, or to leaking inlet valves under usual conditions. The plant under discussion has had but little of

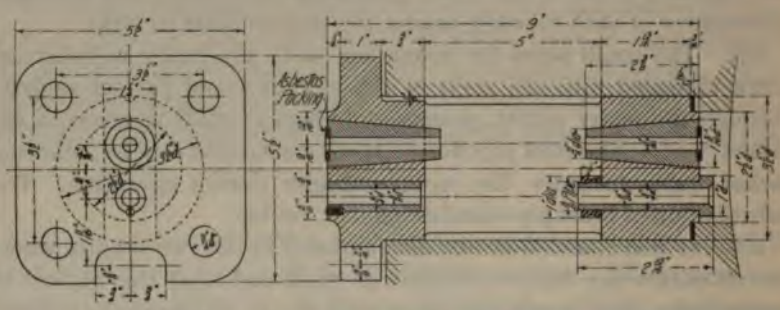


FIG. 24 DETAILS OF IGNITER PLUG

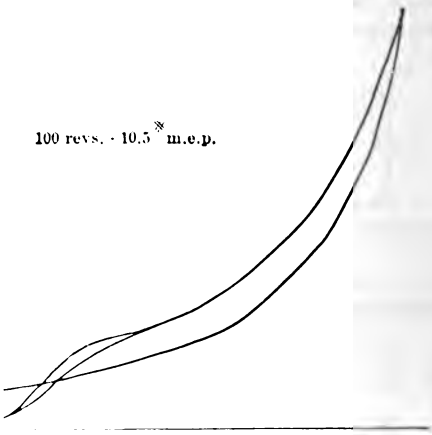
any such trouble. Miss-fires are due to wet gas, faulty plugs or magnetos and weak mixtures.

113 An indicator diagram showing premature ignition is shown in Fig. 25. The maximum pressure indicated in this instance was 385 lb. gage per sq. in.

114 With the type of ignition gear in use there is an interval between the release of the magneto lever and the opening of the igniter terminals. There is also an appreciable time required to complete combustion. This time element being approximately constant, correct ignition requires that the timing of the release shall vary to some extent with the speed of rotation. The ignition gear may then be linked to the speed-adjusting device in such manner as automatically to maintain proper timing of the ignition at all speeds.

GOVERNING

ıg the adjustable speed-governing apparatus
s it was desired to ascertain these quantitative
nition and speed of rotation, and the results of
t were conducted are given in Appendix No. 1.
author has been able to learn, the method of
·nished by the makers consisted in allowing the
ıarge pipe to flow through adjustable leakage
f the governor, back into the suction connection
: blowing engines as designed, this bypassing
ıg the suction stroke of the gas pump; hence



TOR DIAGRAM OF PREMATURE COMBUSTION

gas which was contained in the discharge duct
ımp and inlet valve was subject to this control,
ſter the pressure in the duct discharged through
further bypassing occurred, the remainder of
ıp passing on into the motor cylinder whether
blowing engines could not be governed in this

noted, at the power house a system of throttle
ıpplied; and at the blowing engines, governors
been applied which allow bypassing to occur
ıd discharge strokes of the pump. Speed regu-
ather difficult and unsatisfactory on account of
ariations in the mean effective pressure, due

to weak and variable mixtures under this condition. [illegible] the relation between bypass-valve opening and mean effective pressure, for the speed regulating apparatus now in use at the blowing engines. The character of the curve, however, varies considerably with the quality and pressure of the gas.

CYLINDERS, PISTONS, RODS, VALVES, ETC.

118 The average life of a motor cylinder is about four or five years, during which time the wear as measured on a diameter is about three-eighths inches. The cylinder is then bored out and

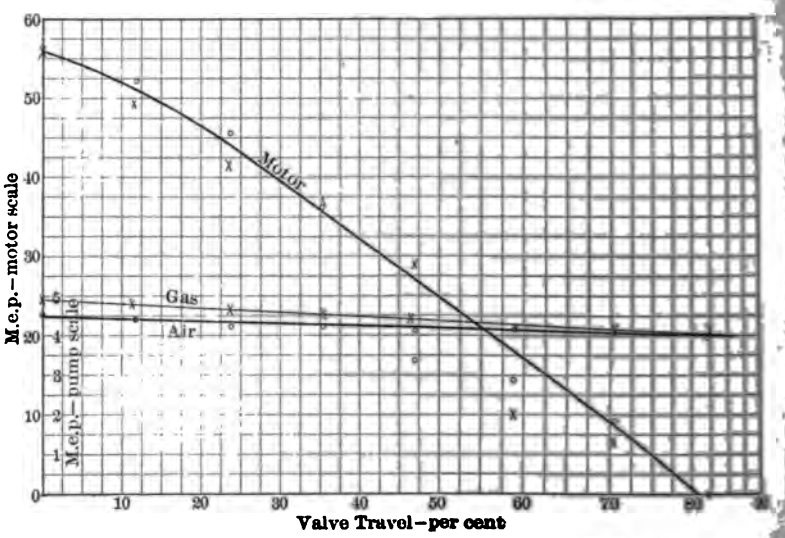


FIG. 26 CALIBRATION OF BYPASS VALVES

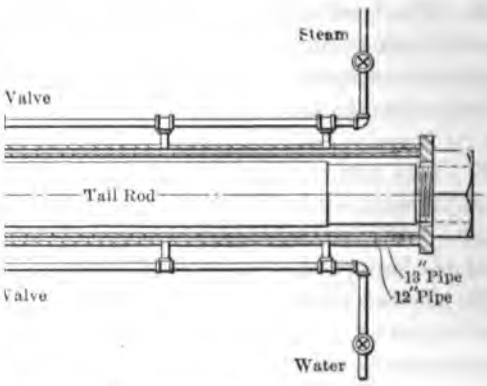
bushed. There are practically no cylinder failures from any cause other than wear.

119 Exhaust ports at power house No. 1 [illegible] become clogged with flue dirt and require cleaning after about th[illegible] months of operation. Exhaust ports at the blowing-engine h[illegible] do not foul at all. The difference is probably due to t[illegible] gas at the blowing-engine houses, and possibly in some ee[illegible] the precipitation of moisture and dirt in the 96-in. headers.

120 Cylinder relief valves require cl[illegible] out once a month. Jackets of cylinders and heads are c[illegible] nce a year.

stons are inspected only when conditions in-
measured and recorded at the same time.
sts in placing the crank on the dead point and
he cylinder to air or exhaust pressure, the
om the opposite head to indicate leakage, if
Details of a 38½-in. cylinder are shown in

ons have a life of from three to five years.
l failures due to any cause other than wear.
ch have been due to the water connections
ston and wearing a hole through the bottom.
, say $\frac{5}{16}$ in. at the bottom, it is turned over
ylinder. There are at present two standard
v cylinders and 37½ in. for bushed cylinders.



VICE FOR STRIPPING TAIL RODS

nuts, when dismantling a piston, are heated,
he lathe and used again. About half of the
o be split off, the rest being utilized again.
rosion around the studs and nuts, and at the
ston, thus forming what may be called a rust
removed from the piston either by means of
in Fig. 27 or by means of screw jacks and
former, the concentric pipes are first cooled
at the end of the tail rod set up; steam is
he pipes at atmospheric pressure to lengthen
epeated until the rod is free from the piston.

When it becomes necessary to remove the piston rod, the piston is broken away, either with dynamite or under the drop hammer.

124 The wear of piston rods occurs principally at the end of the stroke and amounts to about a quarter of an inch on the diameter in three years. It is then turned and will suffice for two or three years more.

125 The average life of the motor cylinder heads is not well established, but it may be set at three years or more. A few of the original heads at the blowing engines are still in service. Failures of these occur principally at the junction of the jacket wall and the main flange on each side of the inlet valve chamber, but this trouble has been substantially eliminated by employing proper fillets. Some heads have developed cracks through the inner wall; two or three have had the inner walls blown entirely away, but this was found due to faulty castings.

126 The inlet valves last about three years before turning and about the same time after they are turned down. They do not require grinding-in except when new. Stems are broken occasionally near the top yoke. Little cleaning of the inlet valve or the ports is necessary.

127 Gas pump cylinders and heads require cleaning every six to eight months on account of dirt getting into the clearance near the bottom. By feeding a little kerosene into the suction pipe, cleaning of the pump valves is avoided.

128 Cylinder heads are packed principally with $\frac{1}{16}$-in. woven wire insertion asbestos sheet. Piston joints are made up either with $\frac{1}{32}$-in. wetted asbestos paper, or with a paste of litharge and glycerine, or with another form of packing known under the trade name of "900." All give satisfactory results.

129 The life of the $1\frac{7}{16}$-in. snap piston rings is about two years. The openings are securely dowelled in place near the bottom of the cylinder, being thus effectively closed by the piston, which is always in contact with the bottom of the cylinder.

130 The piston rods are packed with four cast-iron rings of the Walker type in a casing exterior to the head. Packings are overhauled about every six months to renew broken springs and rings. Casings are trued up at the time of overhauling the piston once in two or three years.

131 The swinging connections for the piston water supply require to be packed about twice a year. The life of the brass goose necks is about two years.

ons require keying up on the left side once a
side once in two months. The main bearings
justments.
inlet cams is about six years. Wear of the steel
occurs on four teeth at the end of four or five
ıen shifted on the shaft so that unworn teeth are
nlet valve opening.
ves are operated through heavy push rods driven
. High inertia stresses are thus developed at
)eeds. With present inlet valve springs which
)mpression of 2500 to 3500 lb. at the blowing
:aves contact with the cam at about 65 to 70
original push rods have been broken by the result-
nd new and stronger rods have been made.
.y stated the shaft of the 2000-h.p. engine is of
ıd it has been the cause of no trouble whatever.
owever, several shaft breakages at the 1000-h.p.
shafts forged in one piece and operate at 100 r.p.m.
.e no investigation relative to the stresses in these
that their life would have been longer had they
type and of present diameters.
0-h.p. engines there has also been trouble with
d fastenings due to inertia stresses set up by the
ıe governor is driven from the layshaft, consider-
l on the mechanism due to reversal of the torque
ıe point of each cam passes under the roller. Some
atures at the 1000-h.p. engines was experienced,
r holes through the flange of the cylinder head
.tor connections were substituted.

OPERATING COSTS

sumption at the blowing engines amounts to about
h.p. hour at the blowing cylinder, equivalent to
)er h.p. year of 8760 hours. This is equivalent
steam coal which has a heating value of 28,000,000
uming the price of such coal to be $2 per ton,
s $11.58 per delivered h.p. year of 8760 hours.
ting costs at blowing-engine house No. 2 for the
ollows. A continuous output of 6000 h.p. at the
as assumed, which is as nearly correct as possible,
ıe various costs were itemized.

OPERATING COSTS AT BLOWING-ENGINE HOUSE NO. 2, 1907

Item	Cost per d.h.p. year
Producing labor	$4.504
Labor to repairs and maintenance	0.320
Material to repairs and maintenance	1.152
General	3.962
Total operating cost	$9.94

The total cost of fuel and operation under the conditions assumed is therefore $21.52 per h.p. year of 8760 hours.

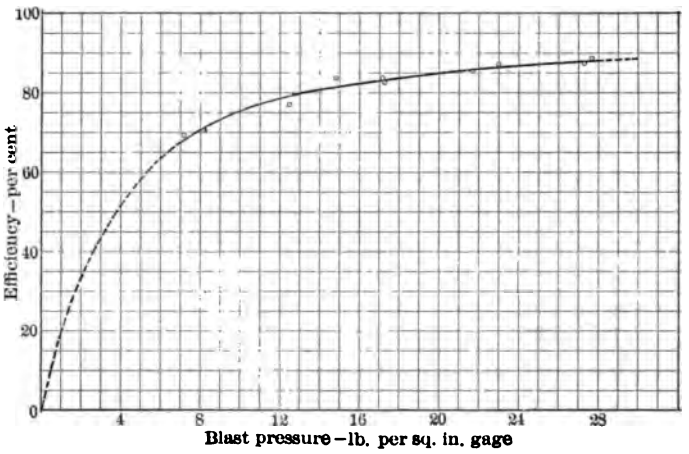


FIG. 28 GROSS MECHANICAL EFFICIENCY CURVE

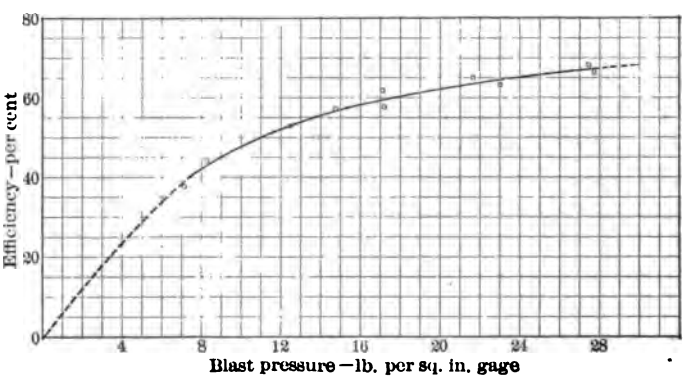
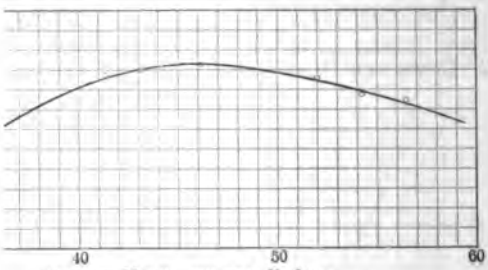


FIG. 29 NET MECHANICAL EFFICIENCY CURVE

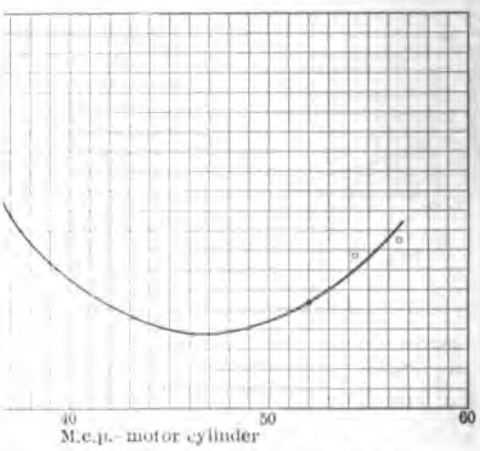
ED QUANTITATIVE RESULTS

ıl pertaining to this subject has already been eading of General Notes Relating to Operation. rials, data upon which are tabulated in Appen- on one of the blowing engines from which deduc- le upon the performance of the engine under f operation.



Average M.e.p.–motor cylinders

ANSFORMING EFFICIENCY OF MOTOR CYLINDER



EAT CONSUMED PER MOTOR H.P-HR.

gulation during these trials was by throttle ly, at least one trial being made under each con- t various blast pressures. In the tabulation, d in pairs, the several blast pressures intended 10, 15, 20 and 25 lb. per sq. in. nominal gage pected that the bypass method of regulation

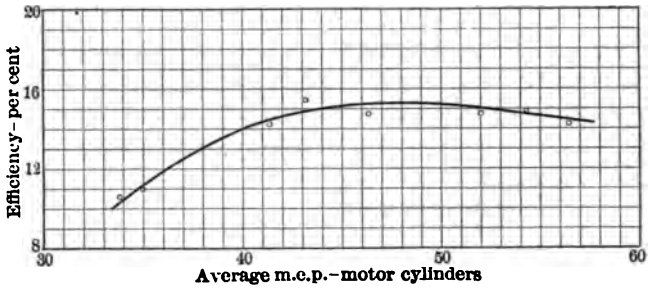


FIG. 32 COMBINED HEAT TRANSFORMING EFFICIENCY OF MOTOR AND PUMP CYLINDERS

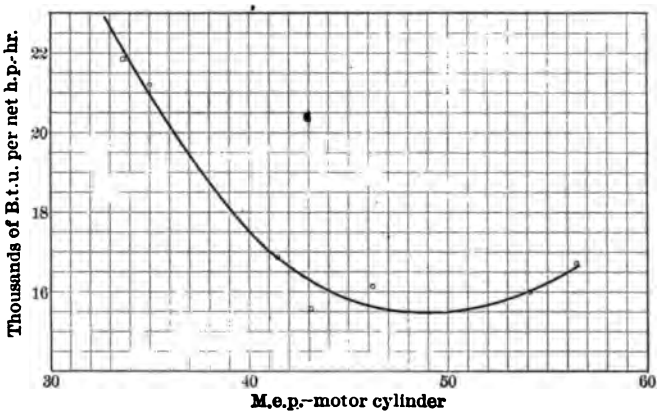


FIG. 33 HEAT CONSUMED PER NET I.H.P-HR.

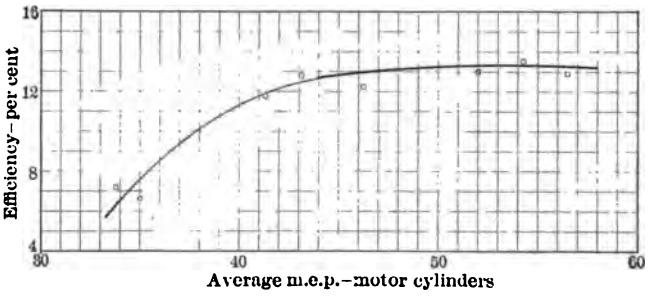
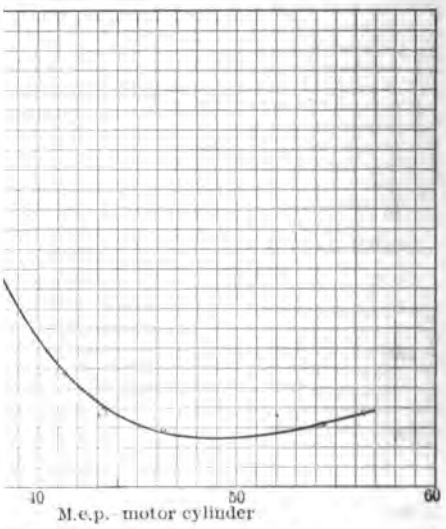


FIG. 34 COMBINED HEAT TRANSFORMING EFFICIENCY OF MOTOR PUMP AND BLOWING CYLINDERS

: due to reduced pump work, etc., but such
to be proven, the blast horsepower efficien-
r the same figure under corresponding load

; the gross mechanical efficiency of the mech-
e blast pressure. It is the ratio of the sum
· horsepowers to the total indicated motor
ıeasure of the degradation due alone to the
he mechanism. Fig. 29 represents the net
the engine, or the ratio of useful work in



T CONSUMED PER BLAST H.P-HR.

otal indicated work in the motor cylinders,
ss due to the sum of pump work and mechan-
ure, which might be termed the "real" me-
l be the ratio of work delivered at the blow-
rence between motor work and pump work;
ndicated horsepower, to net indicated motor

et i.h.p. occurring in the tabulated material
trials is herewith defined as the difference
ted horsepower of the motor cylinders, and
power of the pumps. Having in mind the

above definition, the curves relating to heat-transforming efficiency, and heat consumption, indicated in Figs. 30 to 35 are self-explanatory.

143 Figs. 36 and 37 are measures of the degradation due to pump work, the upper curve in each figure representing throttle test and the lower curve bypass governing test. The curves would have been modified in some degree, had the gas supply pipe and venturi meter been of larger dimensions.

144 Figs. 38 and 39 show the losses due to friction of the mechanism. Figs. 40 and 41 indicate the losses occurring due to incomplete

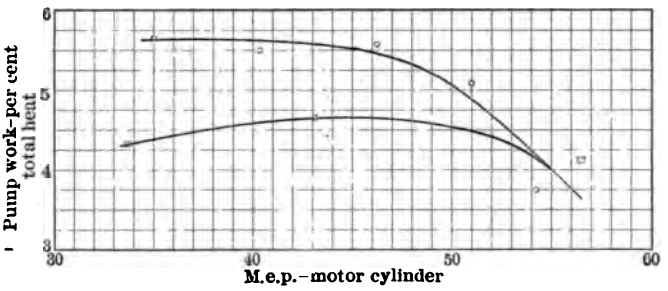


FIG. 36 PUMP WORK—PER CENT

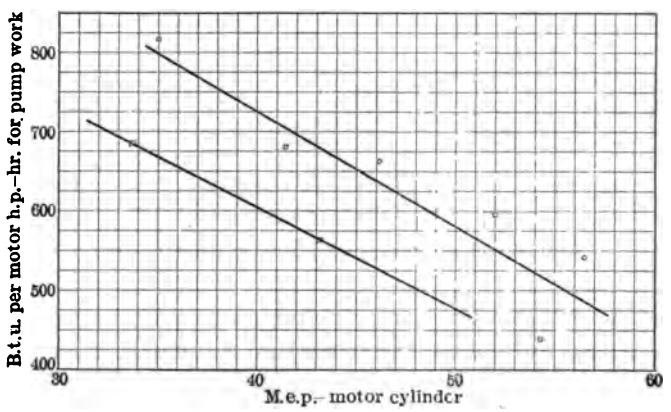
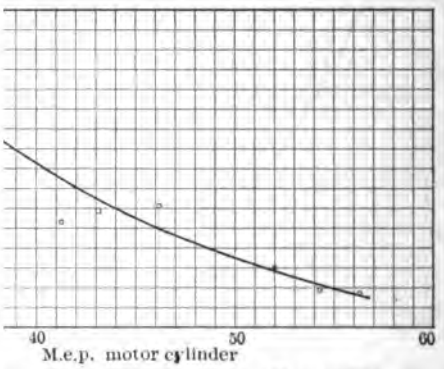


FIG. 37 PUMP WORK—B.T.U. PER MOTOR H.P-HR.

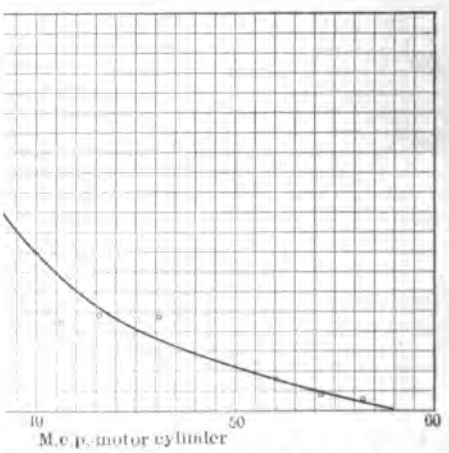
combustion in the motor cylinders under the various load conditions. As will be noted the minimum loss due to this cause is about 30 per low cent of the total heat supplied to the engine and accounts for the conversion efficiency of less than 15 per cent shown by these engines.

145 The diagrams of jacket losses shown in Figs. 42 and 43 apparently indicate that losses due to this cause are somewhat erratic

13 an attempt was made to modify these dis-
ng a speed factor, with indifferent success.
wn is believed to be considerably less than
the four-stroke cycle type.
epresent the sensible heat in the exhaust or
ce.



ON LOSS—PER CENT OF TOTAL HEAT



N LOSS—B.T.U. PER MOTOR H.P-HR.

t of the various horsepowers plotted against
e and Fig. 47 is a diagram of the correspond-
the motor indicated horsepower and referred
In Fig. 46 the respective straight line locii of

the motor horsepower and pump horsepower were produced in broken line to intersect the zero axis. The corresponding intercepts show the probable respective values of these quantities at zero blast-pressure. The difference between these two values will then be the probable friction under conditions of zero blast-pressure. From these assumed prob-

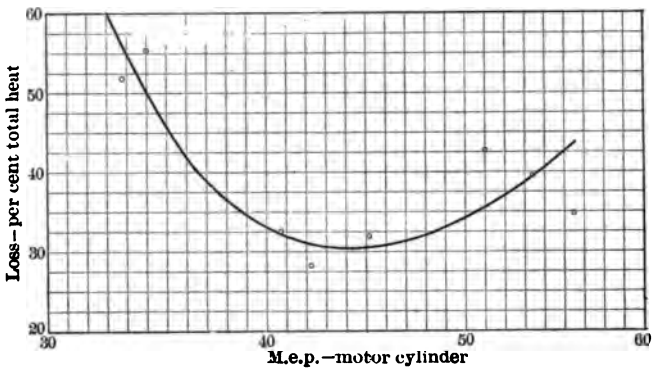


FIG. 40 INCOMPLETE COMBUSTION—PER CENT OF TOTAL HEAT

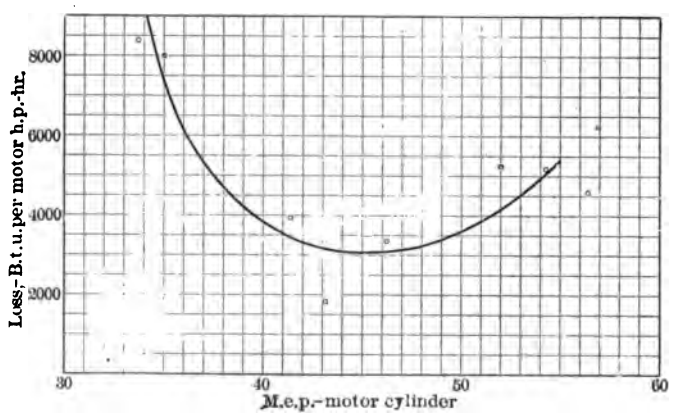
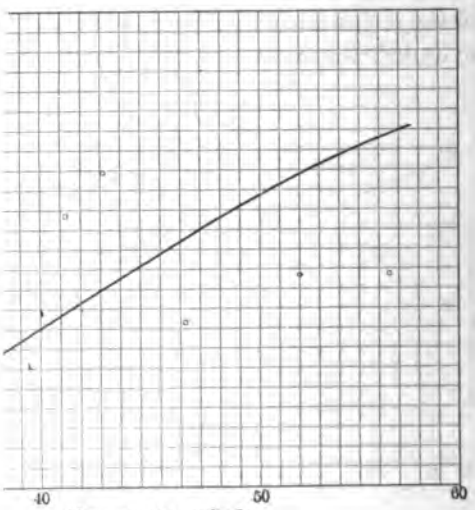


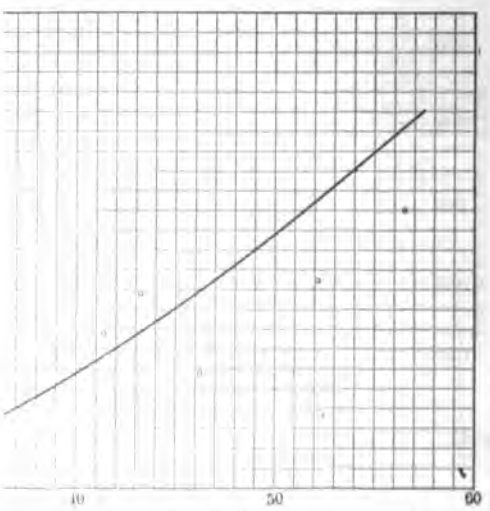
FIG. 41 INCOMPLETE COMBUSTION—B.T.U. PER MOTOR H.P-HR.

able values, corresponding figures were calculated to apply to the percentage chart of Fig. 47, and the respective percentage curves were produced, as shown in broken line, to meet these values.

148 It will be observed that the horsepower of friction at constant speed varies in considerable degree, and inversely with the torque.



CKET LOSS—PER CENT OF TOTAL HEAT



KET LOSS—B.T.U. PER R.P.M. PER HR.

This may be explained in whole or in part, when it is
the pressure at the bearing is a differential between that due to the
inertia of the reciprocating parts and that due to the pressure in the
motor cylinder, the inertia pressure being in excess. The bearing

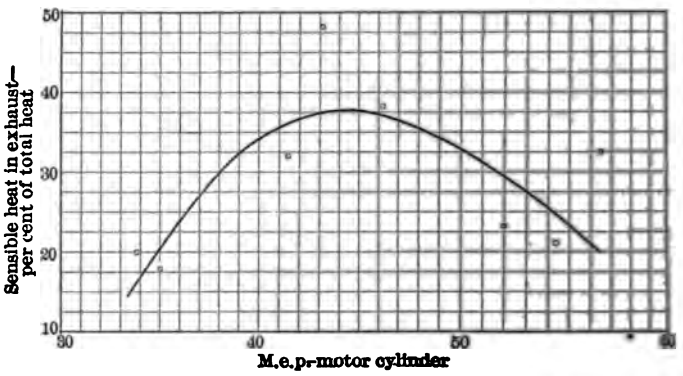


FIG. 44 SENSIBLE HEAT IN EXHAUST—PER CENT OF TOTAL HEAT

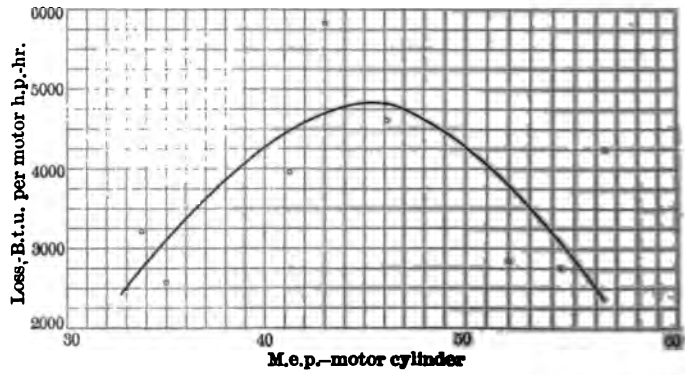
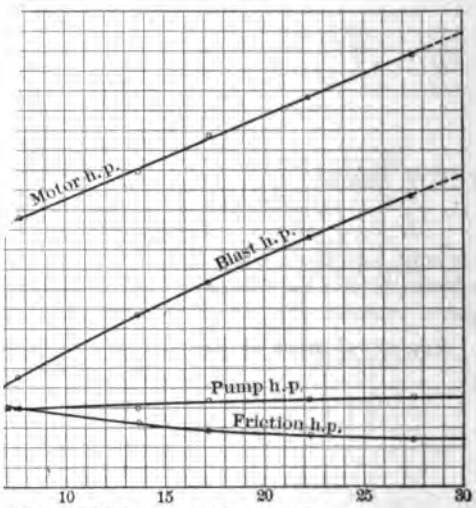


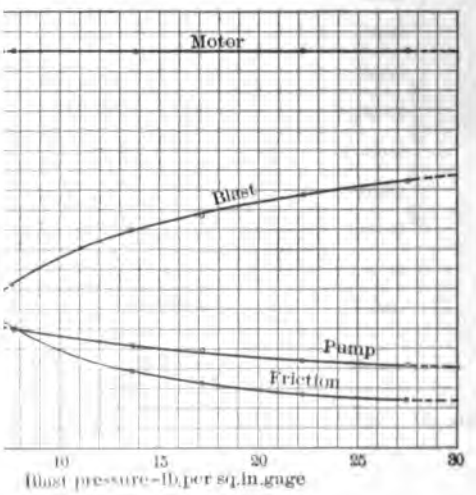
FIG. 45 SENSIBLE HEAT IN EXHAUST—B.T.U. PER MOTOR H.P-HR.

pressures at the dead points are therefore reduced by the pressures of compression and explosion.

149 Figs. 48 and 49 are efficiency and heat consumption curves obtained from tests of the 1000-h.p. engines.



URVES OF H.P. AND BLAST PRESSURE



S OF $\frac{\text{H.P.}}{\text{Motor H.P.}}$ AND BLAST PRESSURE

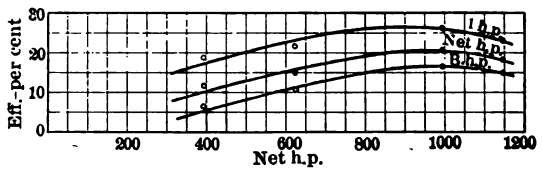


FIG. 48 CURVES OF EFFICIENCY FOR 1000-H.P. ENGINES

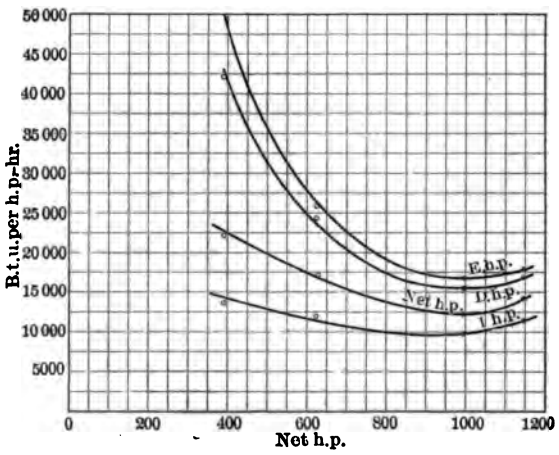
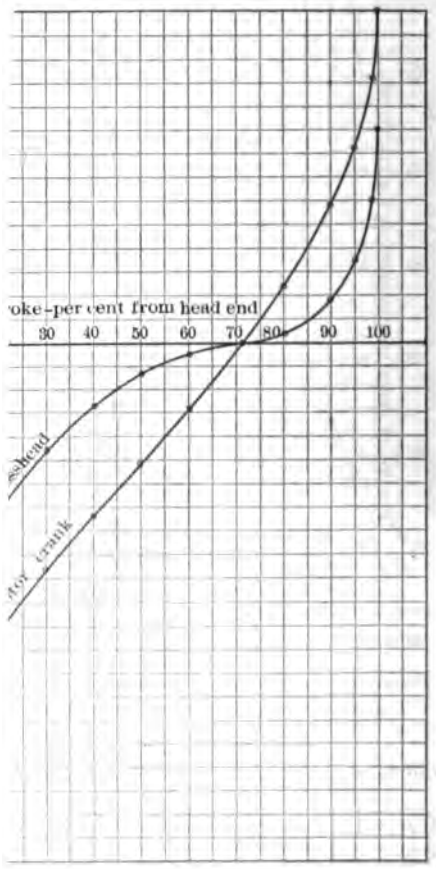


FIG. 49 CURVES OF HEAT CONSUMPTION FOR 1000-H.P. ENGINES

APPENDIX No. 1

ERMINE RELATION BETWEEN POINT OF AND SPEED OF ROTATION

an engine indicator was utilized, the drum motion m the gas pump crosshead. A cord attached to the r was connected first to the magneto lever, and



ONS OF MOTOR CRANK AND CROSSHEAD FOR ANY ITION OF PUMP CROSSHEAD

second to a crank arm on the igniter stem. In this manner the timing of the magneto release, and of the opening of the igniter terminals, both relative to the motion of the gas pump crosshead, were obtained. This investigation was conducted by E. E. Kiger and the results are shown in the form of curves in Figs. 50 to 54 inclusive.

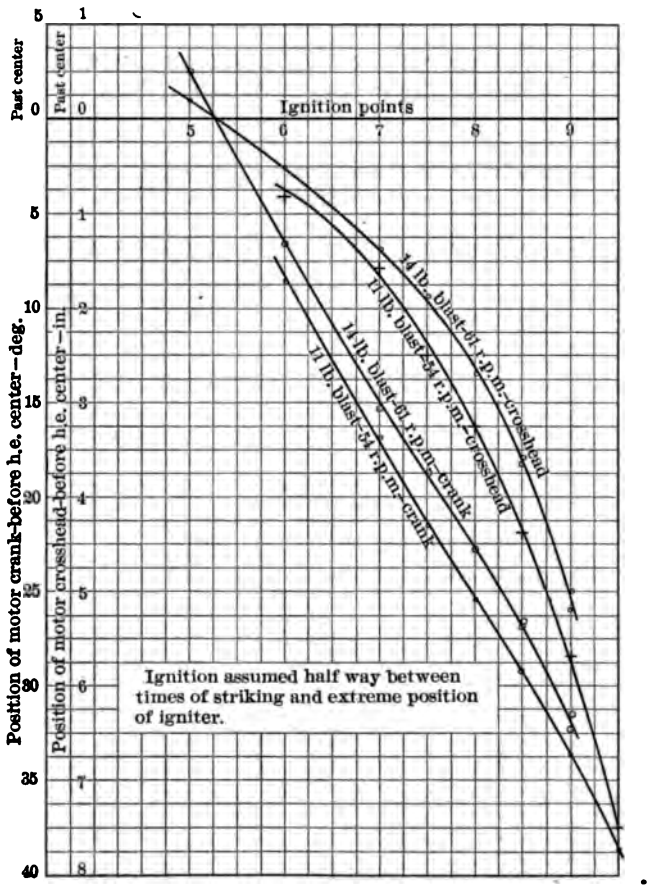


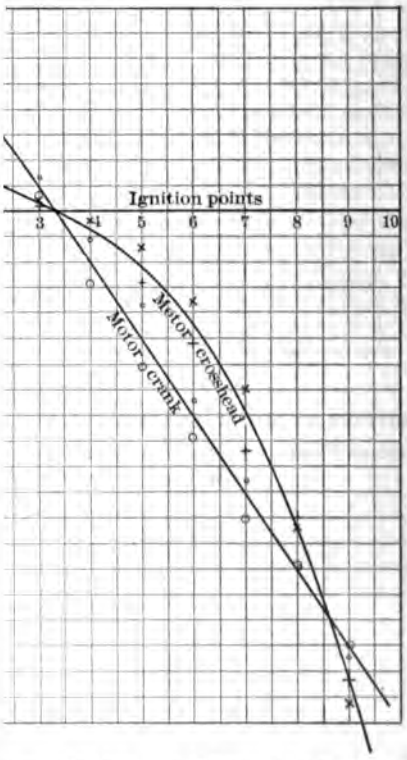
FIG. 51 POSITIONS OF MOTOR CRANK AND CROSSHEAD FOR VARIOUS IGNITION POINTS WHEN IGNITER OPENS

151 Following is the explanation of the curves as taken from Mr. Kiger's report.

152 "Curves of Fig. 50 are diagrams of the relative positions of motor crank and motor crosshead to the pump stroke or crosshead, and were drawn by laying out the various positions from the relative crank angles of the engine.

153 "These diagrams were used to locate ignition points relative to motor crank and crosshead after having determined them by experiment relative to the pump crosshead.

g. 51—Diagrams were taken on an indicator pulled
he pencil being attached by cord to the igniter.
is one that is half way between the point of striking
position of the igniter. Motor cards were taken
ards at different points of ignition from 5 to 9 on the
engine. A series of cards was taken at two speeds,
as was used at all ignitions to produce good motor



OTOR CRANK AND CROSSHEAD AT RELEASE OF MAG-
ER FOR VARIOUS IGNITION POINTS

posite side of the engine. Using curves of Fig. 50,
rred from pump base to motor base as shown on

-Location of motor crank and crosshead is shown at
r the various ignition points on the arbitrary scale.
nilar manner to those on Fig. 51, except that the cord
lever of the magneto, instead of to the igniter.
—While Fig. 51 shows positions for two speeds, Fig.
ious speeds, under both normal and checked condi-

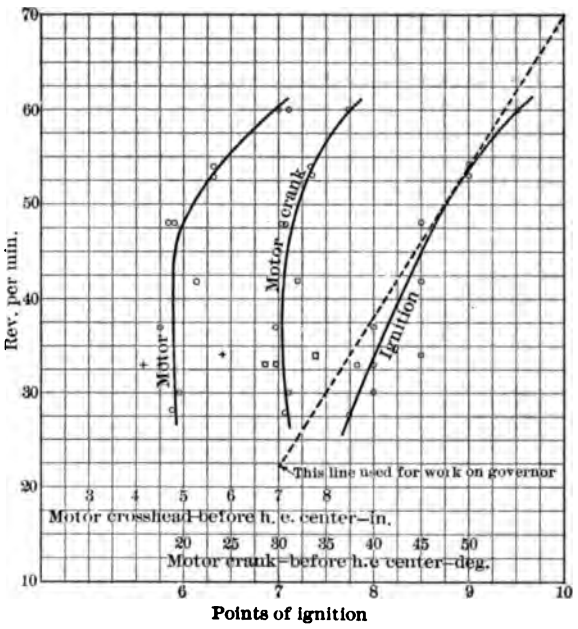


FIG. 53 POSITIONS OF MOTOR CRANK AND CROSSHEAD AND IGNITION POINTS FOR GOOD CARDS AT AVERAGE BLAST AND CHECK CONDITION FOR VARIOUS SPEEDS

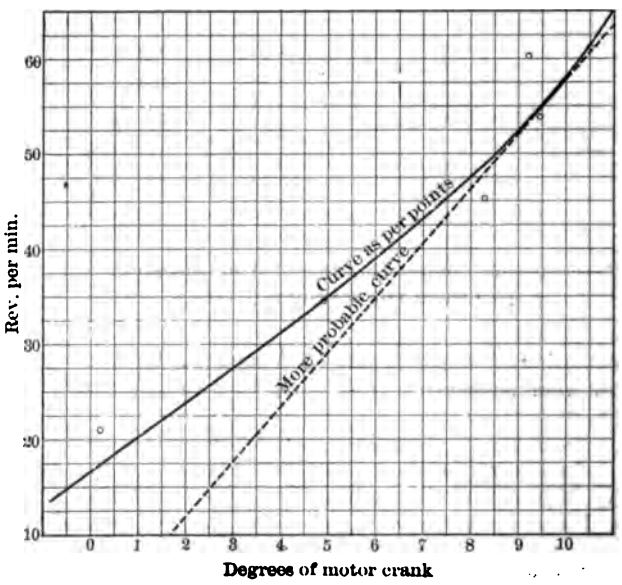


FIG. 54 LAG BETWEEN LEVER RELEASE AND IGNITER OPENING

gine was regulated to give good cards at all speeds.
ontal from left to right, when intersecting a curve,
rect abscissa. A straight line, shown dotted, was

54—Curve as per points was made by combining 52
;le of crank of motor between release of magneto lever
were obtained at low speeds, but at zero speed there
e, therefore the more probable curve is as shown

pump was used because of its greater rapidity during
securing greater accuracy of observation than if the
or crosshead had been utilized. Fig. 53 shows that the
;niter circuit occurs under lead angles varying from
37.5 deg. at 60 r.p.m. in order to produce proper timing
ermined from simultaneous indicator diagrams of the
er. The corresponding timing of the release of the mag-
from about 36 deg. at 30 r.p.m. to 47 deg. at 60 r.p.m.
ıbustion was complete, as determined from the in-
work diagrams in the motor cylinder, was maintained
ıld be estimated, at about 10 deg. past the motor crank

APPENDIX No. 2

DIAGRAM SHOWING LOSSES DUE TO AIR AND GAS PUMPS

159 Fig. 56 shows crank circle diagram of the various events for the motor cylinder, the timing of the various events such as opening and closing the inlet and exhaust valves, etc., being indicated in degrees referred to the motor crank dead points.

160 Figs. 55, 57 and 58 are pressure diagrams taken at the various pump cylinders and connections as noted thereon. Fig. 57 is an average of head and crank diagrams referred to a pump-piston motion base line. Figs. 55 and 58 are similar diagrams referred to the motion of the motor piston. The method of governing at the time these diagrams were taken was throttling. From the diagrams the pressure losses through the various parts of the apparatus supplying air and gas may be deduced. This pump work, amounting to 20 per cent or more of the indicated horsepower, is one of the limiting factors preventing the attainment of the best economy from the engines as constructed.

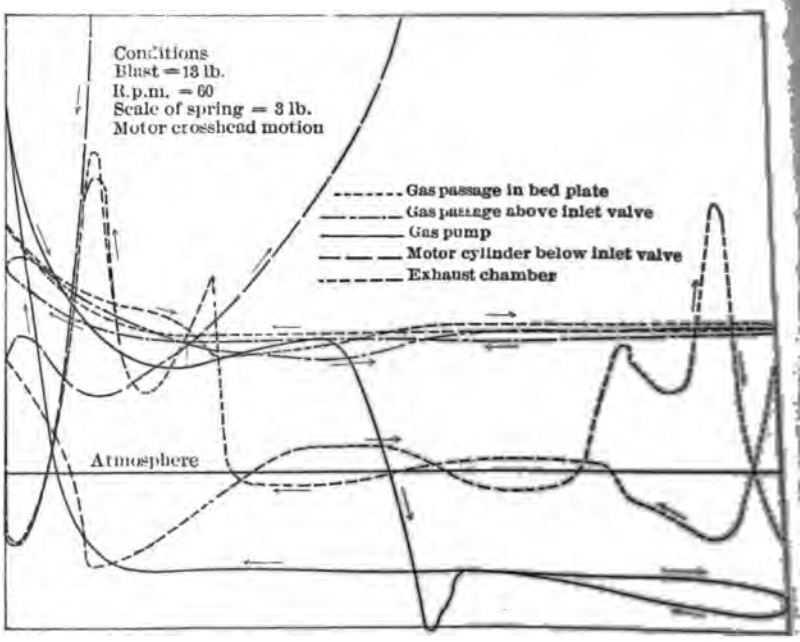


FIG. 55 AVERAGE DIAGRAMS FROM GAS PUMP (MOTOR BASE)

FIG. 56 CRANK-CIRCLE DIAGRAM OF MOTOR

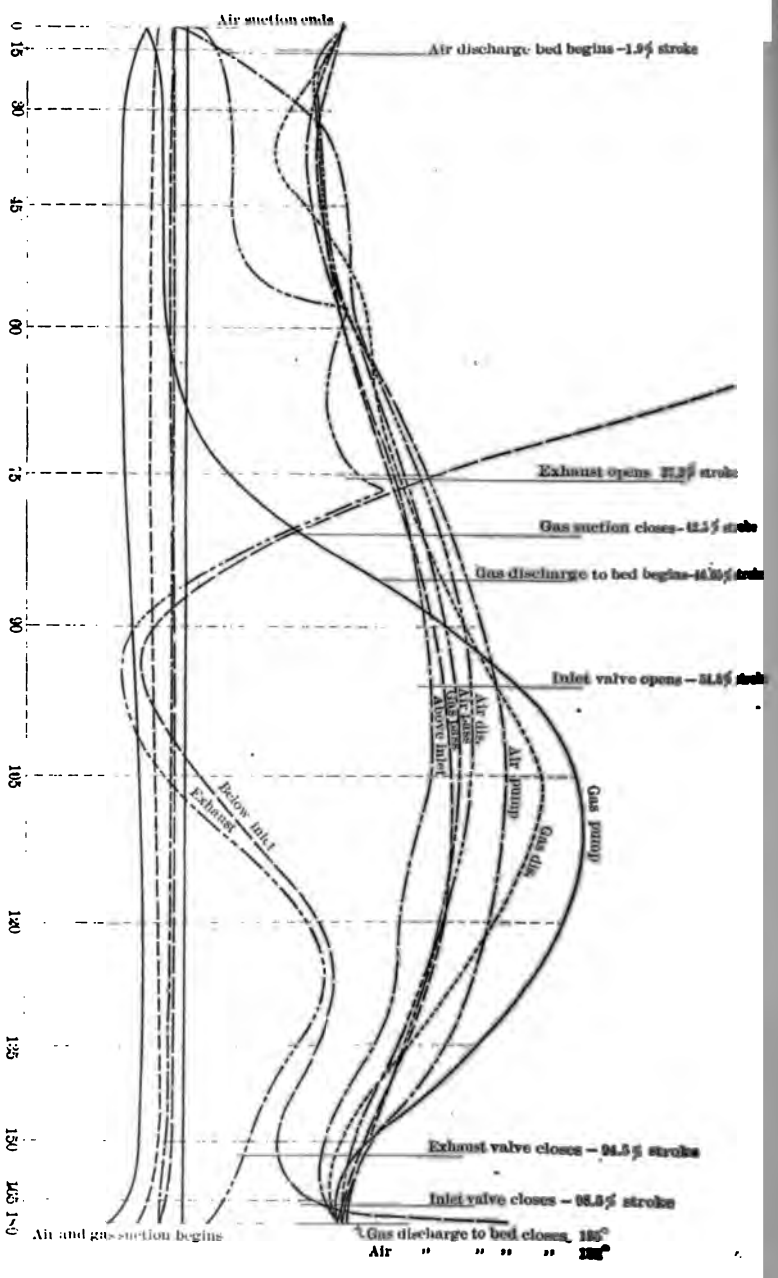
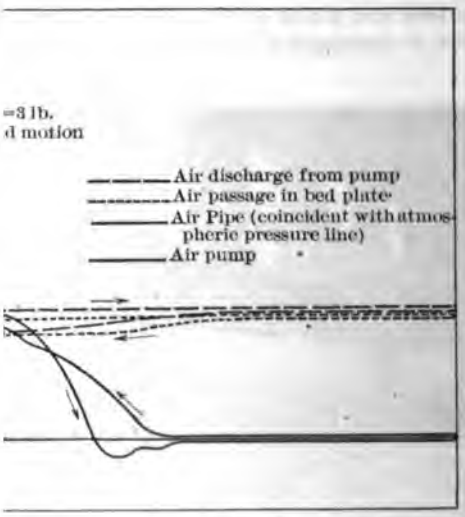


FIG. 57 AVERAGE DIAGRAMS FROM GAS AND AIR PUMPS (PUMP BASE)



GRAMS FROM AIR PUMP (MOTOR BASE)

APPENDIX No. 3

DATA UPON EFFICIENCY TRIALS OF 2000-H.P. BLOWING ENGINE

161 The following matter is principally the tabulation of data and calculated results from a series of efficiency trials at one of the blowing engines.

162 The measurement of the gas was by means of a 16-in. venturi meter in the gas-supply pipe leading to the pumps. The general arrangement of meter, surge tank and piping are shown in Fig. 59. The meter is a little small for the service, in consequence of which the blast pressure could not be carried beyond

FIG. 59 GENERAL ARRANGEMENT OF METER AND PIPING

8 lb. gage. The coefficient of the meter was assumed to be unity, and no corrections were made for dirt or moisture in the gas, same not being observed.

163 The composition of the gas was obtained by means of an Orsat apparatus which was equipped with a palladium tube for the determination of hydrogen. A continuous sample was taken and analyzed at the end of the trial; another was taken from each of the exhaust pipes and analyzed after the completion of the run. Correction of the carbon-monoxide in the exhaust gases was made as shown in the correction chart for Orsat apparatus, Fig. 60, plotted from the data of Dennis and Edgar. For determining the calorific power of the gas, the high heating value of the gas, as calculated from the analysis, was used.

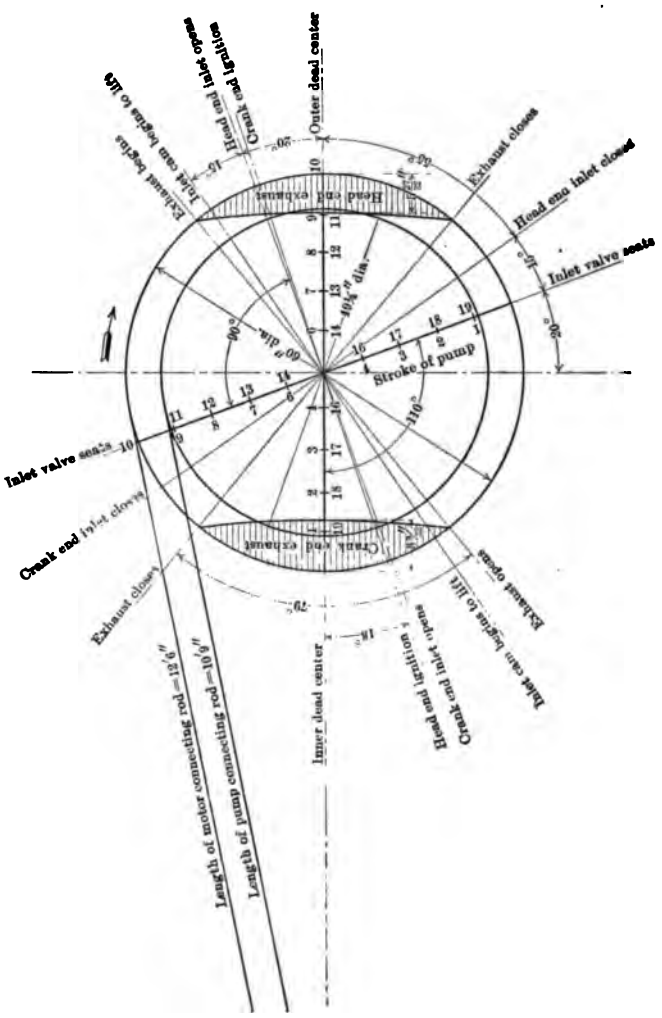


FIG. 56 CRANK-CIRCLE DIAGRAM OF MOTOR

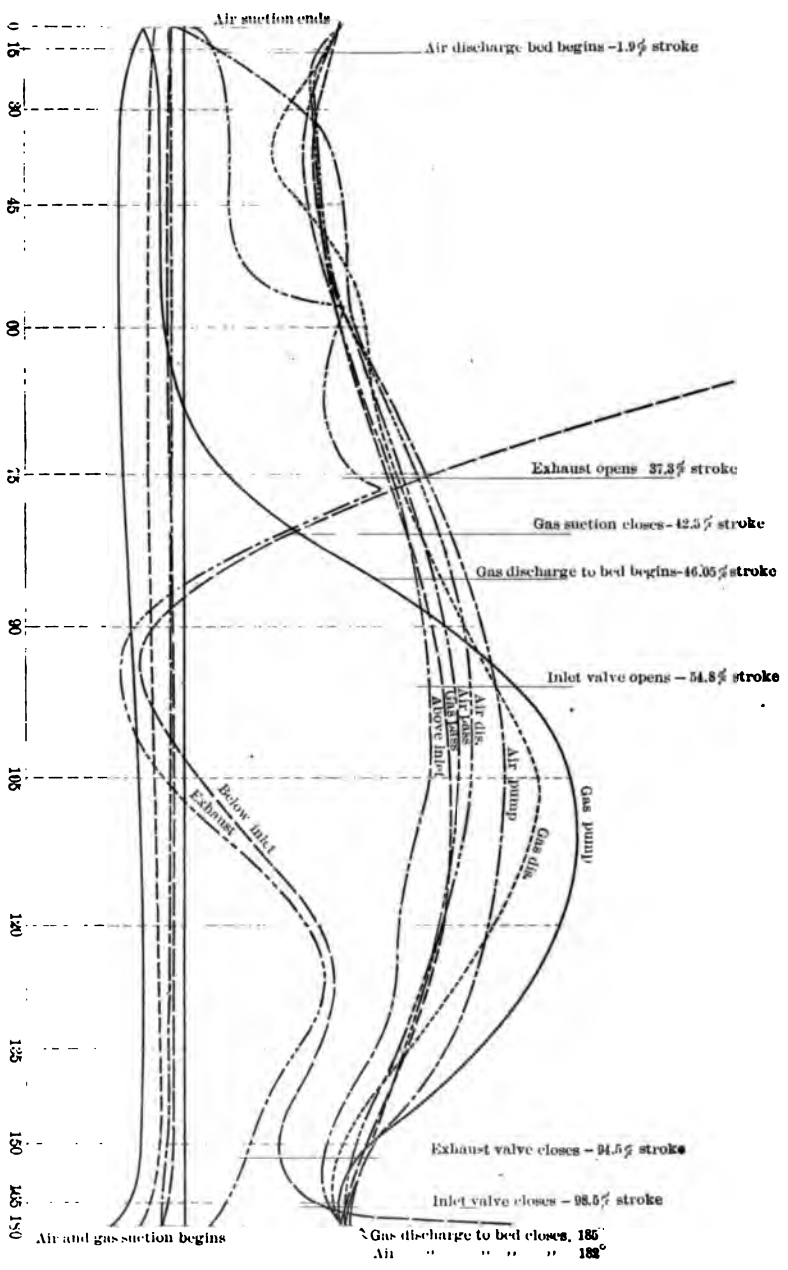


FIG. 57 AVERAGE DIAGRAMS FROM GAS AND AIR PUMPS (PUMP BASE)

:rogen in exhaust gases
per min.
min.
er min.

:al nitrogen.....[3]

$CO\Big) =$ excess air .....[4]

$7\ A$

16
$28\left(CO\right)$

ENGINE AT 7.65-LB. BLAST PRESSURE

TA RELATING TO TESTS

.....	27	37
.....	April 9	April 15
.....	60	60
.....	Throttle	Bypass
.....	9	9
.....	16 in., area 1.396 sq. ft.	
.....	6½ in., area 0.213 sq. ft.	
.....	13	13
.....	57.92	57.60
.....	7 37	12 61
.....	16.38	22.23
.....	36 6	47.5
.....	29.18	29.63
.....	14.58749	14.99743
In	13.99642	14.19526
.....	0.959481	0.9465
.....	0.3380	0.3863

Jacket Water

Right Side

.....	8100	11,100
.....	39	39.5
.....	118	150

Left Side

.....	8650	10,700
.....	39	39.5
.....	168.1	154.4

APPENDIX No. 3

DATA UPON EFFICIENCY TRIALS OF 2000-H.P. BLOWING ENGINE

161 The following matter is principally the tabulation of data and calculated results from a series of efficiency trials at one of the blowing engines.

162 The measurement of the gas was by means of a 16-in. venturi meter in the gas-supply pipe leading to the pumps. The general arrangement of meter, surge tank and piping are shown in Fig. 59. The meter is a little small for the service, in consequence of which the blast pressure could not be carried beyond

FIG. 59 GENERAL ARRANGEMENT OF METER AND PIPING

28 lb. gage. The coefficient of the meter was assumed to be unity, and no corrections were made for dirt or moisture in the gas, same not being observed.

163 The composition of the gas was obtained by means of an Orsat apparatus, which was equipped with a palladium tube for the determination of hydrogen. A continuous sample was taken and analyzed at the end of the trial; another was taken from each of the exhaust pipes and analyzed after the completion of the run. Correction of the carbon-monoxide in the exhaust gases was made as shown in the correction chart for Orsat apparatus, Fig. 60, plotted from the data of Dennis and Edgar. For determining the calorific power of the gas, the high heating value of the gas, as calculated from the analysis, was used.

.....	35.56	33.42
.....	38.19	30.08
.....	43.13	36.26
.....	37.79	32.74
.....	67.43	51.66
.....	75.69	51.45
.....	70.99	57.14
.....	68.10	51.79
.....	245.62	280.29
.....	256.29	285.41

RESULTS OF TESTS

.....	27	37
.....	April 9	April 15
.....	Throttle	Bypass
.....	7.1	8.2
.....	57.92	57.60
ı. ft.....	193,846	222,635
.....	196,963	224,851
ns.....	99.291	91.771
.....	97.7199	90.8666
.....	19,247,230	20,431,500
.....	1,333.90	1,280.01
.....	154.67	132.50
.....	272.21	212.04
.....	501.91	565.70
.....	907.02	935.47
....	405.11	369.76
ıe, per cent.....	69.63	71.28
.....	37.63	44.19
ɔnditions.....	145.32	173.93
conditions.....	213.72	237.99
rd conditions.....	386.22	393.56
.....	14,492	15,961
.....	21,220	21,841
.....	38,348	36,117
.....	17.64	15.94
.....	11.99	11.65
.....	6.64	7.05
.....	3.66	2.95
B.t.u.....	10,667,950	10,592,600
hr., B.t.u.....	1,761,670	2,462,630
r hr., by difference, ...	3,422,750	4,121,030

RIBUTION OF TOTAL HEAT

.....	6.64	7.05
.....	5.65	4.29
.....	5.35	4.60
.....	9.15	12.05
.....	55.43	51.84
.....	17.18	20.17

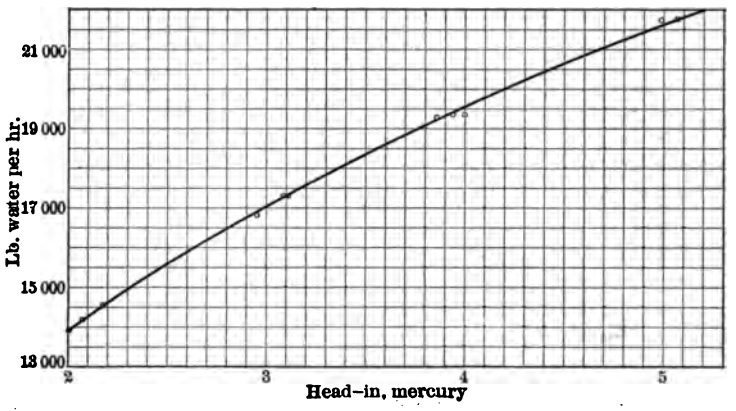


FIG. 62 ORIFICE CALIBRATION CURVES

DILUTION COEFFICIENT OF EXHAUST GASES

Let

N_0 = nitrogen in fuel
N_1 = nitrogen in theoretic air for combustion
N_2 = nitrogen in actual air supplied
N_3 = nitrogen in excess air supplied
N = nitrogen in products of combustion
X = dilution coefficient

$$X = \frac{N_2}{N_1} = \frac{N_3}{N_2 - N_3} = \frac{N_1 + N_3}{N} \quad \text{[1]}$$

168 Equation [1] is true for volume or weight analysis, and if little or no nitrogen exists in the fuel, then $N_1 = N$, and, as is usual,

$$X = \frac{N}{N - N_3} \quad \text{[2]}$$

$$= \frac{N}{N - \frac{79}{21}(O - CO)} \quad \text{for volume analysis}$$

$$= \frac{N}{N - \frac{7677}{2323}\left(O - \frac{16}{28}CO\right)} \quad \text{for weight analysis}$$

169 In the present instance, where the fuel contained appreciable nitrogen, the following methods and notation were used, the volume analysis of the exhaust gases being reduced to equivalent weight analysis:

A = theoretic air required in lb. per min.
O = weight fraction of oxygen in exhaust gases
CO = weight fraction of CO in exhaust gases

RESSURES AND HORSEPOWERS

.....	28	36
.....	April 9	April 15

EAN EFFECTIVE PRESSURES

.....	31.62	40.02
.....	42.28	37.99
.....	46.68	44.87
.....	44.50	33.69
.....	4.45	4.06
.....	4.51	3.86
.....	5.46	4.57
.....	4.85	4.20
.....	5.42	4.62
.....	5.47	4.60
.....	6.15	5.26
.....	5.92	4.72
.....	11.18	9.84
.....	11.50	10.22

HORSEPOWERS

.....	301.69	381.30
.....	403.39	361.96
.....	445.37	427.51
.....	424.57	320.99
.....	36.26	33.04
.....	36.62	31.30
.....	44.49	37.19
.....	39.38	34.06
.....	62.24	52.98
.....	62.69	52.65
.....	70.63	60.32
.....	67.85	54.02
.....	445.67	391.71
.....	453.36	402.34

RESULTS OF TESTS

.....	28	36
.....	April 9	April 15
.....	Throttle	Bypass
.....	14.8	12.5
.....	58	57.92
ft. .	193,760	234,581
	197,546	235,570
s	100 314	92.13
	98.391	91.7431
	19,436,800	21,611,970
	1575 02	1491.76
	156 75	135.59
	263 41	219.97

Fuel Gas Analysis by Volume

23 CO_2, per cent	8.8	12.8
24 O, per cent	0.3	0.1
25 CO, per cent	28.1	26.2
26 H, per cent	1.0	0.7
27 N (by difference), per cent	61.8	60.2
28 Weight per cu. ft., standard conditions, lb	0.0814588	0.0834342
29 Weight per cu. ft., test conditions, lb	0.08016984	0.0826120
30 Heating value per cu. ft., standard conditions, B.t.u.	99.291	91.771
31 Heating value per. cu. ft., test conditions, B.t.u	97.7199	90.8666

Exhaust Gas Analysis by Volume

Right Side		
32 CO, per cent	6.5	9.0
33 O, per cent	13.6	11.8
34 CO, per cent	4.0	4.3
35 N (by difference), per cent	75.9	74.9
Left Side		
36 CO, per cent	5.8	8.6
37 O, per cent	13.4	11.8
38 CO, per cent	4.1	4.4
39 N (by difference), per cent	76.7	75.2

CYLINDER PRESSURES AND HORSEPOWERS

Number of test	27	37
Date of test, 1909	April 9	April 15

Mean Effective Pressures

Motor		
Right head	21.46	37.40
Crank	28.73	33.26
Left head	47.21	33.03
Crank	42.60	26.40
Air pump		
Right head	4.37	4.13
Crank	4.71	3.73
Left head	5.30	4.48
Crank	4.66	4.06
Gas pump		
Right head	5.88	4.53
Crank	5.74	4.53
Left head	6.19	5.01
Crank	5.95	4.55
Air tub		
Head	6.17	7.06
Crank	6.51	7.20

Horsepowers

Motor		
Right head	204.47	354.37
Crank	273.73	315.15
Left head	449.81	320.34
Crank	405.89	269.18

IAS ANALYSIS BY VOLUME		
.....	10.4	10.7
.....	0.2	0.2
.....	25.7	26.4
.....	1.3	0.5
.....	62.4	62.2
lb.....	0.0819455	0.0826587
.....	0.077834	0.08396471
ditions, B.t.u..	92.149	91.75
ıs, B.t.u.....	87.5255	87.8562
IAS ANALYSIS BY VOLUME		
Right Side		
.....	9.1	11.0
.....	11.4	10.5
.....	2.1	0.5
.....	77.4	78.0
Left Side		
.....	9.1	9.5
.....	11.1	11.1
.....	2.0	1.1
.....	77.8	78.3
ESSURES AND HORSEPOWERS		
.....	29	30
.....	April 10	April 10
N EFFECTIVE PRESSURES		
.....	39.66	44.06
....	45.64	44.84
.....	48.76	41.95
.....	50.79	41.49
.....	5.28	4.41
....	5.56	4.25
....	6.02	4.73
.....	5.45	4.42
.....	5.96	4.57
.....	5.89	4.82
.....	6.31	5.07
....	6.20	4.76
....	12.73	12.74
.....	12.76	12.66
HORSEPOWERS		
.....	400.25	433.06
..... .	460.60	440.73
.....	492.09	412.32
.....	512.58	407.80
....	45 51	37.02
.....	47.75	35.55
.....	51.89	39.71
.....	46.81	36.97

TEST OF NO. 2 GAS ENGINE AT 13.65 LB. BLAST PRESSURE

DATA RELATING TO TESTS

1	Number of test	28	36
2	Date of test, 1909	April 9	April 15
3	Duration of test, min	60	60
4	Method of regulation	Throttle	Bypass
5	Sets of indicator diagrams	9	9
6	Venturi meter		
	Pipe diameter, in	16, area 1.396 sq. ft.	
	Throat diameter, in	6½, area 0.213 sq. ft.	
7	Number of venturi observations	13	13
8	R.p.m. of engine	58	57.92
9	Gas pressure, in. water	7.81	11.01
10	$P_1 - P_2$, in. water	16.43	24.72
11	Gas temperature, deg. fahr	38	42.5
12	Barometer, in. mercury	29.13	29.62
13	Absolute pipe pressure, lb. per sq. in	14.57882	14.93479
14	Absolute throat pressure, lb. per sq. in	13.98594	14.04277
15	Ratio $\frac{P_2}{P_1}$	0.95933	0.9403
16	$Mf\left(\frac{P_2}{P_1}\right)$	0.3385	0.406

JACKET WATER

	Right Side		
17	Water used per hr., lb	8000	10,900
18	Temperature inlet, deg. fahr	39	39.5
19	Temperature discharge, deg. fahr	180.8	149.7
	Left Side		
20	Water used per hr., lb	12,950	10,750
21	Temperature inlet, deg. fahr	39	39.5
22	Temperature discharge, deg. fahr	172.8	145.1

FUEL GAS ANALYSIS BY VOLUME

23	CO_2, per cent	8.8	12.6
24	O, per cent	.2	.2
25	CO, per cent	28.4	26.0
26	H, per cent	1.0	1.0
27	N (by difference), per cent	61.6	60.2
28	Weight per cu. ft., standard conditions, lb	0.0814471	0.0831388
29	Weight per cu. ft., test conditions, lb	0.079886	0.0837898
30	Heating value per cu. ft., standard conditions, B.t.u.	100.314	92.13
31	Heating value per cu. ft., test conditions, B.t.u.	98.391	91.7431

EXHAUST GAS ANALYSIS BY VOLUME

	Right Side		
32	CO_2, per cent	8.0	9.0
33	O, per cent	12.5	11.0
34	CO, per cent	3.0	5.1
35	N (by difference), per cent	76.5	74.9
	Left Side		
36	CO_2, per cent	8.0	9.2
37	O, per cent	12.3	11.2
38	CO, per cent	2.8	4.8
39	N (by difference) per cent	76.9	74.8

.....	13	13
.....	51.65	59.72
.....	11.75	12.75
.....	38.33	25.51
.....	60	61
.....	29.43	29.52
.....	14.86824	14.9485
.....	13.48510	14.02797
.....	0.096973	0.03842
.....	0.4968	0.412

Jacket Water

Right side

.....	12,600	12,200
.....	40.5	40.5
.....	178.3	154.3

Left side

.....	13,100	12,650
.....	40.5	40.5
.....	172.7	167

:L Gas Analysis by Volume

.....	12.7	11.3
.....	0.2	0.1
.....	26.5	24.1
.....	0.7	0.7
.....	59.9	63.8
tons, lb.	0.0834002	0.0827742
lb.....	0.0799028	0.0795783
conditions, B.t.u ...	92.794	84.61
litions, B.t.u.....	88.9072	81.3433

UST Gas Analysis by Volume

Right Side

.....	11.2	11.7
.....	9.8	9.8
.....	4.6	2.4*
.....	74.4	76.1

Left Side

.....	11.6	10.2
.....	9.6	10.1
.....	4.0	2.6
....	74 8	77.1

PRESSURES AND HORSEPOWERS

.. ..	32	31
.....	April 12	April 12

:AN Effective Pressures

..	48.89	45.51
.	52 16	50.06
	52 70	50.06
..	54 31	48.41

14 I.h.p. of blowing cylinder	899.08	794.05
15 I.h.p. net	1154.86	1136.20
16 I.h.p. friction	255.83	342.15
17 Gross mechanical efficiency of engine, per cent	83.76	77.07
18 Net mechanical efficiency of engine, per cent	57.08	53.23
19 Cu. ft. gas per i.h.p-hr., standard conditions	123.02	157.25
20 Cu. ft. gas per net h.p-hr., standard conditions	167.78	206.46
21 Cu. ft. gas per blast h.p-hr., standard conditions	215.52	295.42
22 B.t.u. per i.h.p-hr	12,341	14,488
23 B.t.u. per net h.p-hr	16,830	19,021
24 B.t.u. per blast h.p-hr	21,620	27,217
25 Efficiency per i.h.p., per cent	20.62	17.57
26 Efficiency per net h.p.	15.12	13.38
27 Efficiency per blast h.p., per cent	11.77	9.35
28 Dilution coefficient	3.45	4.081
29 Potential heat in exhaust per hr., B.t.u.	6,313,100	13,505,700
30 Heat absorbed by jacket water per hr., B.t.u.	2,878,390	2,342,880
31 Sensible heat in exhaust, etc., per hr. by difference, B.t.u.	6,236,880	1,966,690

DISTRIBUTION OF TOTAL HEAT

2 Delivered to the blast, per cent	11.77	9.35
3 Pump work, per cent	5.50	4.19
4 Friction, per cent	3.35	4.03
5 Absorbed by jackets, per cent	14.81	10.84
6 Incomplete combustion, per cent	32.48	62.49
7 Balance by difference, per cent	32.09	9.10

TEST OF NO. 2 GAS ENGINE AT 17.15-LB. BLAST PRESSURE

1 Number of test	29	30
2 Date of test, 1909	April 10	April 10
3 Duration of test, min	60	60
4 Method of regulation	Throttle	Bypass
5 Sets of indicator diagrams	9	9
6 Venturi meter		
Pipe diameter, in	16, area 1.396 sq. ft.	
Throat diameter, in	6¼, area 0.213 sq. ft.	
7 Number of venturi observations	13	13
8 R.p.m. of engine	61.35	59.75
9 Gas pressure, in. water	9.35	14.51
10 P_1-P_2, in. water	27.33	21.78
11 Gas temperature, deg. fahr	39.6	38
12 Barometer, in. mercury	29.53	29.58
13 Absolute pipe pressure, lb. sq. in	14.83071	15.04146
14 Absolute throat pressure	13.84451	14.25553
15 Ratio $\frac{P_2}{P_1}$	0.933503	0.94775
16 $Mf\left(\frac{P_2}{P_1}\right)$	0.427	0.382

JACKET WATER

Right Side		
17 Water used per hr., lb	8975	13,050
18 Temperature inlet, deg. fahr	38	40
19 Temperature discharge, deg. fahr	153.4	178.7
Left Side		
20 Water used per hr	14,800	11,950
21 Temperature inlet, deg. fahr	38	40
22 Temperature discharge, deg. fahr	151	167.70

.....	20.63	24.32
.....	15.79	19.39
.....	13.03	15.83
.....	2.267	2.686
.t.u.....	11,159,000	6,178,480
hr., B.t.u.....	3,481,200	2,998,600
:. by difference,		
.....	6,017,500	5,839,760

STRIBUTION OF TOTAL HEAT

.....	13.03	15.83
.....	4.84	4.93
.....	2.76	3.56
.....	13.38	15.11
.....	42.87	31.14
.....	23.12	29.43

ENGINE AT 27.5-LB. BLAST PRESSURE

.....	33	35
.....	April 13	April 14
.....	60	60
.....	Bypass	Bypass
.....	9	9
.....	16, area, 1.396 sq. ft.	
.....	6¼, area, 0.213 sq. ft.	
.....	13	13
.....	54.45	58.62
.....	11.01	10.94
.....	38.88	51.65
.....	62.6	42
.....	29.08	29.53
ln.....	14.66976	14.88809
. in.....	13.26678	13.0243
....	0.90436	0.8748
.....	0.5025	0.5645

JACKET WATER

Right Side		
.....	18,650	16,300
.....	42.3	40
.....	167.1	147.4
Left Side		
.....	20,000	17,650
.....	42.3	40
.....	169	156.4

. GAS ANALYSIS BY VOLUME

....	12.0	13.1
.....	0.1	0.2
....	25.9	24.3
.....	0.5	1.4
.....	51.5	61.0
lons, lb	0 0832257	0.083047
lb	0 0782805	0.0825485
conditions, B.t.u..	90 054	87.721
ditions, B.t.u.....	84.7031	87.1661

Gas pump		
Right head	73.40	54 07
Crank	71.40	56.91
Left head	76.65	59.98
Crank	75.16	56.20
Air tub		
Head	536.77	523.18
Crank	532.09	514.15

RESULTS OF TESTS

1 Number of test	29	30
2 Date of test, 1909	April 10	April 10
3 Method of regulation	Throttle	Bypass
4 Blast pressure, lb	17.2	17.1
5 R.p.m. of engine	61.35	59.75
6 Gas per hr., standard conditions, cu. ft	241,853	223,940
7 Gas per hr., test conditions, cu. ft	254,630	221,293
8 B.t.u. per cu. ft., standard conditions	92.149	91.759
9 B.t.u. per cu. ft., test conditions	87.5255	92.8562
10 Total B.t.u. in gas per hr	22,286,500	20,548,400
11 I.h.p. of motor cylinders	1,865.52	1,693.91
12 I.h.p. of air pumps	191.96	149.25
13 I.h.p. of gas pumps	295.61	227.16
14 I.h.p. of blowing cylinder	1068.86	1037.33
15 I.h.p. net	1377.95	1317.50
16 I.h.p. friction	309.09	280.17
17 Gross mechanical efficiency of engine, per cent	83.43	84.43
18 Net mechanical efficiency of engine, per cent	57.30	61.24
19 Cu. ft. gas per h.p-hr., standard conditions	129.64	132.20
20 Cu. ft. gas per net h.p-hr., standard conditions	175.52	169.97
21 Cu. ft. gas per blast h.p-hr., standard conditions	226.27	215.88
22 B.t.u. per i.h.p-hr.	11,948	12,131
23 B.t.u. per net h.p-hr	16,174	15,597
24 B.t.u. per blast h.p-hr	20,850	19,809
25 Efficiency per i.h.p., per cent	21.30	20.98
26 Efficiency per net h.p., per cent	15.74	16.32
27 Efficiency per blast h.p., per cent	12.21	12.85
28 Dilution coefficients	3.1	3.149
29 Potential heat in exhaust per hr., B.t.u.	6,243,500	3,048,400
30 Heat absorbed by jacket water per hr	2,715,250	3,282,940
31 Sensible heat in exhaust, etc., per hr. by difference, B.t.u.	8,582,500	9,904,330

DISTRIBUTION OF TOTAL HEAT

32 Delivered to the blast, per cent	12.21	12.85
33 Pump work, per cent	5.56	4.66
34 Friction, per cent	3.53	3.47
35 Absorbed by jacket, per cent	12.18	15.98
36 Incomplete combustion, per cent	28.01	14.84
37 Balance of difference, per cent	38.51	48.20

TEST OF NO. 2 GAS ENGINE AT 22.35-LB. BLAST PRESSURE

1 Number of test	32	31
2 Date of test, 1909	April 12	April 12
3 Duration of test, min	60	60
4 Method of regulation	Throttle	Bypass
5 Sets of indicator diagrams	9	9
6 Venturi meter		
Pipe diameter, in	16, Area, 1.396 sq.ft.	
Throat diameter, in	6½, Area, 0.213 sq.ft.	

RESULTS OF TESTS

.....	33	35
.....	April 13	April 14
.....	Bypass	Bypass
.....	27.3	27.7
.....	54.45	58.62
, cu. ft.....	279,512	325,429
ft.....	297,170	327,501
ions.....	90.054	87.721
.....	84.7031	87.1661
.....	25,171,200	28,546,970
.....	1945.37	2178.06
.....	157.40	203.90
.....	214.86	270.27
.....	1330.28	1447.41
.....	1573.11	1703.89
.....	242.83	256.48
gine, per cent.....	87.52	88.22
ne, per cent.....	68.38	66.45
l conditions	143.68	149.41
ard conditions.....	177.68	191.00
dard conditions.....	210.12	224.84
.....	12,939	13,107
.....	16,001	16,754
.....	18,922	19,723
.....	19.67	19.42
.....	15.91	15.29
.....	13.45	12.90
.....	1.947	2.1732
B.t.u.....	10,106,760	9,909,840
er hr., B.t.u.....	4,880,850	3,815,270
r hr. by difference, ...	5,323,710	9,277,765

TRIBUTION OF TOTAL HEAT

.....	13.45	12.90
.....	3.76	4.13
.....	2.46	2.39
.....	19.39	13.37
.....	39.79	34.71
.....	21.15	32.50

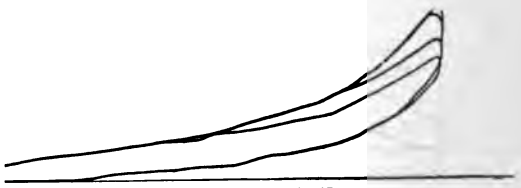
Air pump		
Right head	5.68	4.39
Crank	5.93	4.20
Left head	6.31	4.90
Crank	5.78	4.52
Gas pump		
Right head	5.82	4.64
Crank	5.80	4.85
Left head	6.21	5.31
Crank	5.99	4.96
Air tub		
Head	15.40	14.78
Crank	16.23	15.47

HORSEPOWERS

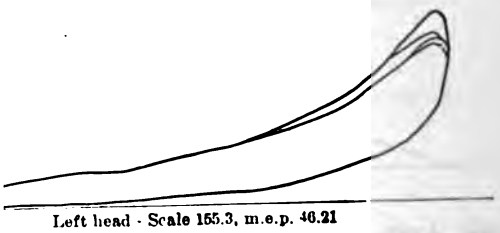
Motor		
Right head	495.81	447.09
Crank	528.98	481.96
Left head	534.45	491.79
Crank	550.78	475.58
Air pump		
Right head	49.20	36.84
Crank	51.18	35.12
Left head	54.66	41.11
Crank	49.89	37.79
Gas pump		
Right head	71.04	54.87
Crank	70.66	57.23
Left head	75.80	62.79
Crank	72.97	58.53
Air tub		
Head	652.53	606.65
Crank	680.09	627.95

RESULTS OF TESTS

1	Number of test	32	31
2	Date of test, 1909	April 12	April 12
3	Method of regulation	Throttle	Bypass
4	Blast pressure, lb	23.0	21.7
5	R.p.m. of engine	61.65	59.72
6	Gas per hr., standard conditions, cu. ft	280,485	234,521
7	Gas per hr., test conditions, cu. ft	292,762	243,937
8	B.t.u. per cu. ft., standard conditions	92.794	84.61
9	B.t.u. per cu. ft., test conditions	88.9027	81.3433
10	Total B.t.u. in gas per hr	26,027,300	19,842,850
11	I.h.p. of motor cylinders	2110.02	1896.42
12	I.h.p. of air pumps	204.93	150.86
13	I.h.p. of gas pumps	290.47	233.42
14	I.h.p. of blowing cylinder	1332.62	1224.60
15	I.h.p. net	1461.62	1512.14
16	I.h.p. friction	282.00	277.54
17	Gross mechanical efficiency of engine, per cent	86.64	85.37
18	Net mechanical efficiency of engine, per cent	63.16	65.10
19	Cu. ft. gas per i.h.p-hr., standard conditions	132.93	123.67
20	Cu. ft. gas per net h.p-hr., standard conditions	154.57	155.09
21	Cu. ft. gas per h.p-hr., standard conditions	210.48	189.96
22	B.t.u. per i.h.p-hr	12,335	10,464
23	B.t.u. per net. h.p-hr	14,343	13,122
24	B.t.u. per blast h.p-hr	19,531	16,072

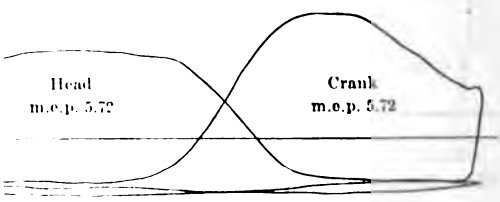


Right head - Scale 149.7, m.e.p. 31.45

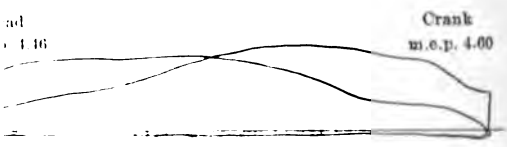


Left head - Scale 155.3, m.e.p. 46.21

'ERAGE MOTOR DIAGRAM—TEST 28—10 LB. BLAST



Right gas - Scale 10.35



Right adr - Scale 10.36

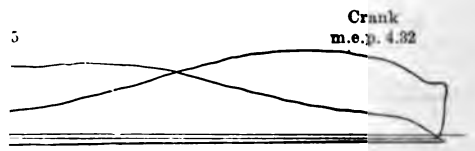
VERAGE PUMP DIAGRAM—TEST 28—10 LB. BLAST

EXHAUST GAS ANALYSIS BY VOLUME

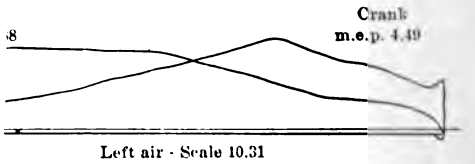
Right Side		
32 CO_2, per cent	12.1	12.1
33 O, per cent	8.5	8.7
34 CO, per cent	4.5	3.5
35 N (by difference), per cent	74.8	75.7
Left Side		
36 CO_2, per cent	12.4	11 6
37 O, per cent	8.2	9.0
38 CO, per cent	4.1	3.4
39 N (by difference), per cent	75.3	76 0

CYLINDER PRESSURES AND HORSEPOWERS

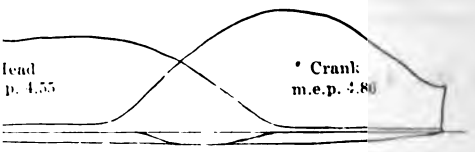
Number of test	33	35
Date of test, 1909	April 13	April 14
MEAN EFFECTIVE PRESSURES		
Motor		
Right head	51.74	51.90
Crank	53.42	55.37
Left head	56.44	59.59
Crank	55.59	59.01
Air pump		
Right head	4.88	5.79
Crank	4.92	5.79
Left head	5.61	6.88
Crank	5.20	6.34
Gas Pump		
Right head	4.64	5.47
Crank	4.85	5.46
Left head	5.34	6.32
Crank	5.12	6.06
Air tub		
Head	17.36	17.60
Crank	18.39	18.53
HORSEPOWERS		
Motor		
Right head	463.44	500.47
Crank	478.48	533.93
Left head	505.53	574.63
Crank	497.92	569.08
Air pump		
Right head	37.33	47.69
Crank	37.51	47.52
Left head	42.92	56.66
Crank	39.64	52.08
Gas pump		
Right head	50.02	63.49
Crank	52.18	63.24
Left head	57.57	73.35
Crank	55.09	70.19
Air tub		
Head	649.67	709.10
Crank	680.61	738.31



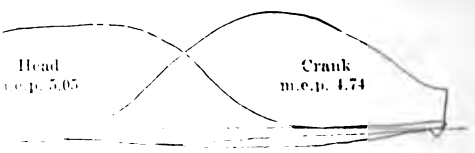
Right air - Scale 10.36



Left air - Scale 10.31

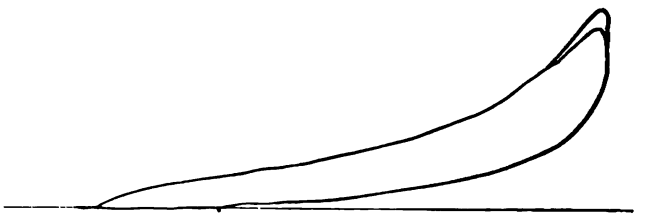


Left gas - Scale 10.35

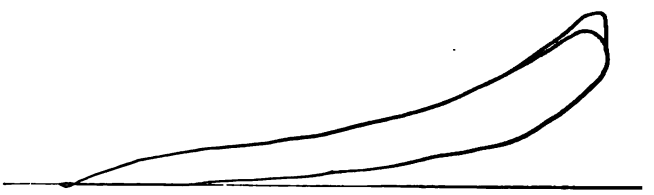


Left gas - Scale 10.14

AGE PUMP DIAGRAM—TEST 30—15 LB. BLAST

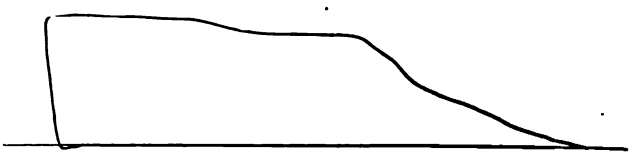


Right head - Scale 149.7, m.e.p. 44.15



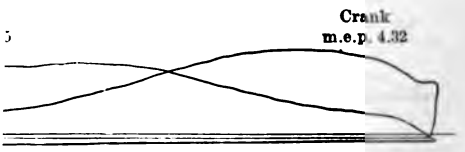
Left head - Scale 155.3, m.e.p. 42.35

FIG. 65*a* AVERAGE MOTOR DIAGRAM—TEST 30—15 LB. BLAST

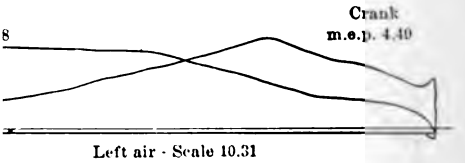


Crank - Scale 21.05, m.e.p. 12.60

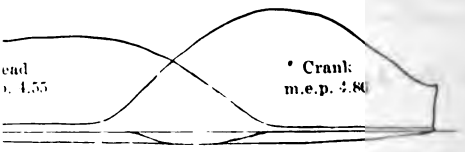
FIG. 65*b* AVERAGE COMPRESSOR DIAGRAM—TEST 30—15 LB. BLAST



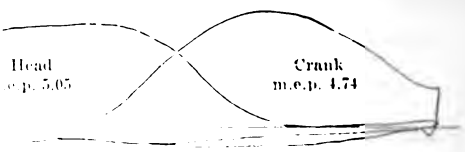
Right air - Scale 10.36



Left air - Scale 10.31

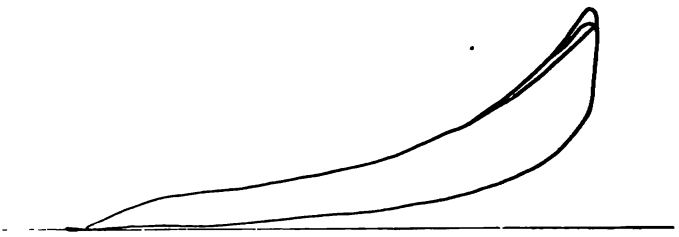


Left gas - Scale 10.35

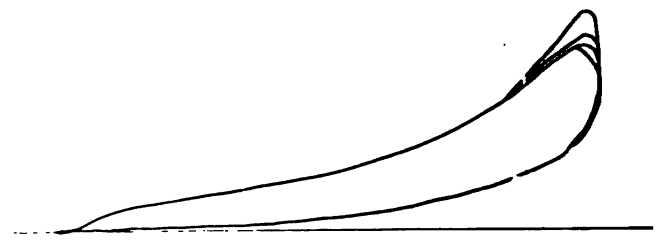


Left gas - Scale 10.44

GE PUMP DIAGRAM—TEST 30—15 LB. BLAST-

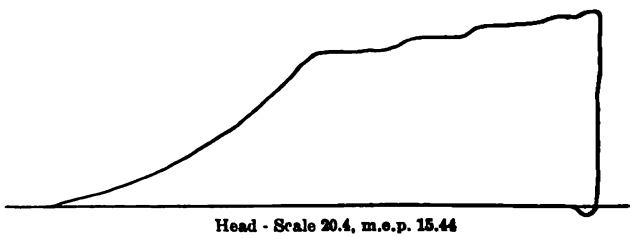


Right head - Scale 149.7, m.e.p. 48.92



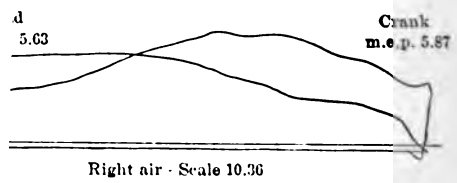
Left head - Scale 155.3, m.e.p. 52.63

FIG. 66*a* AVERAGE MOTOR DIAGRAM—TEST 32—20 LB. BLAST

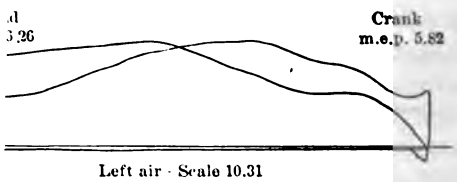


Head - Scale 20.4, m.e.p. 15.44

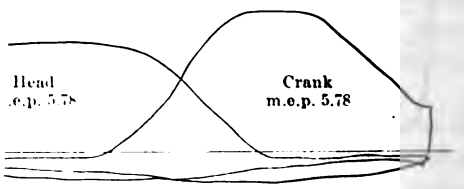
FIG. 66*b* AVERAGE COMPRESSOR DIAGRAM—TEST 32—20 LB. BLAST



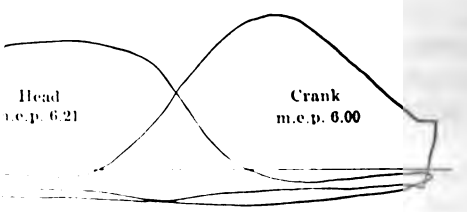
Right air - Scale 10.36



Left air - Scale 10.31

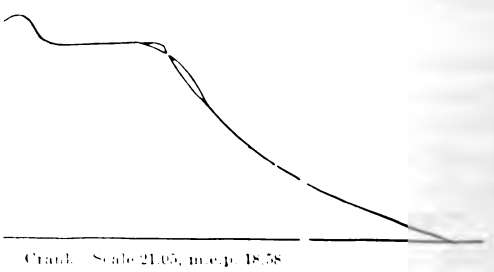


Right gas - Scale 10.35

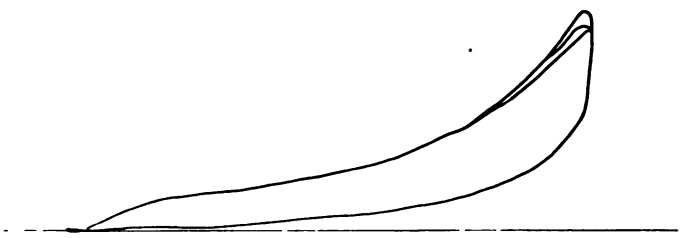


Left gas - Scale 10.44

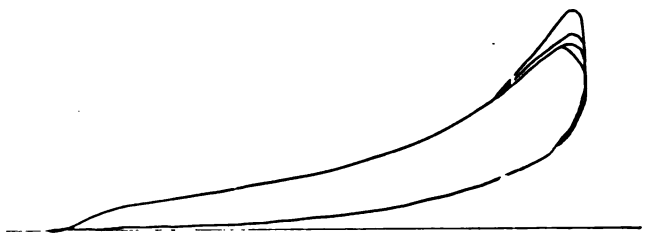
AGE PUMP DIAGRAM—TEST 32—20 LB. BLAST



AGE COMPRESSOR DIAGRAM—TEST 35—25 LB. BLAST

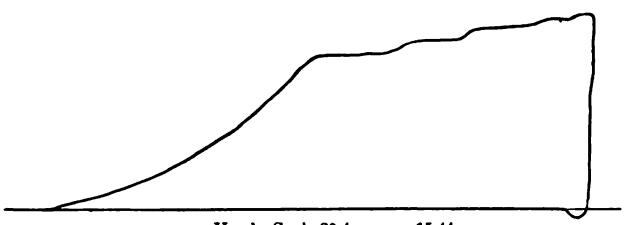


Right head - Scale 149.7, m.e.p. 48.92



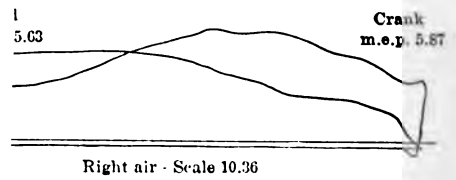
Left head - Scale 155.3, m.e.p. 52.63

FIG. 66*a* AVERAGE MOTOR DIAGRAM—TEST 32—20 LB. BLAST

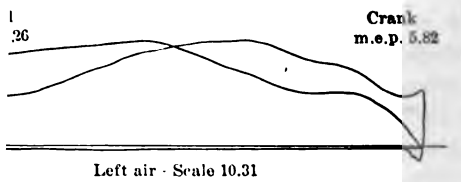


Head - Scale 20.4, m.e.p. 15.44

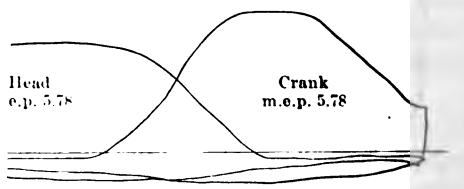
FIG. 66*b* AVERAGE COMPRESSOR DIAGRAM—TEST 32—20 LB. BLAST



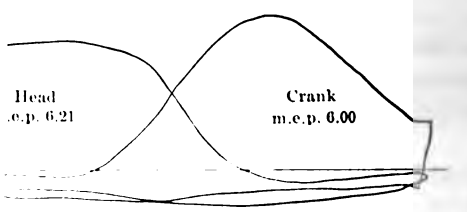
Right air - Scale 10.36



Left air - Scale 10.31

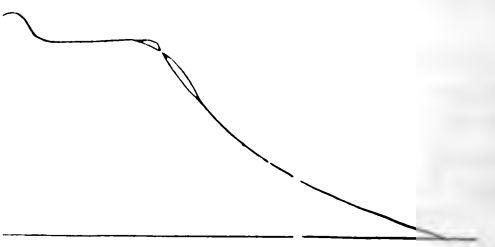


Right gas - Scale 10.35



Left gas - Scale 10.44

.GE PUMP DIAGRAM—TEST 32—20 LB. BLAST



Crank - Scale 21.05, m.e.p. 18.58

AGE COMPRESSOR DIAGRAM—TEST 35—25 LB. BLAST

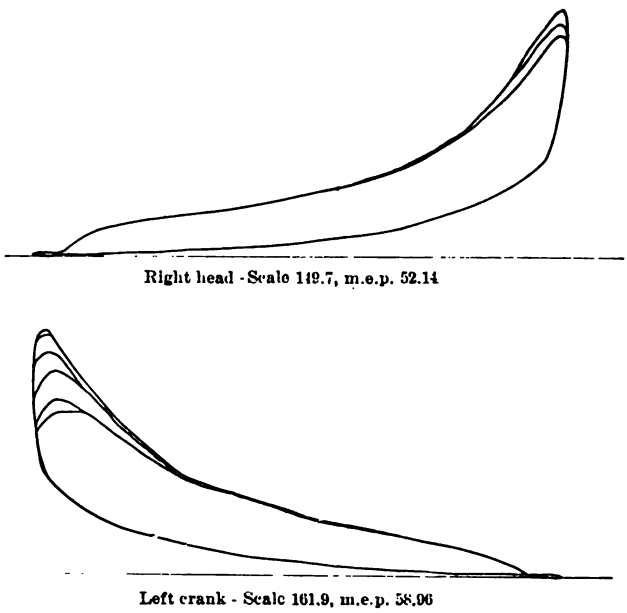


FIG. 67b AVERAGE MOTOR DIAGRAM—TEST 35—25 LB. BLAST

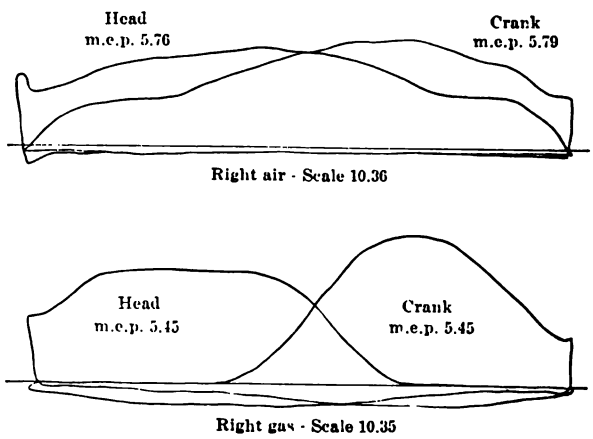


FIG. 67c AVERAGE PUMP DIAGRAM—TEST 35—25 LB. BLAST

DISCUSSION

development of the steam turbine as an effi-
otative speed gives to the metallurgical engineer
ıent of the turbo-multiple stage blowing engines,
in 1904 at Middlesboro, England, and now with
ıines at English, Scotch and Continental works.
ch machines blowing furnaces in this country,
ɔuilding. This bids fair to be the furnace blow-
ıture, which the works' engineer must compare
mplicated reciprocating blowing engine, whether
.

the turbo-blower should prove to be fair over-all
e, cheapness, absence of valve mechanism, les-
l attendance and other operating costs; in short,
ɔperating charges.

some discussion indicating that the gas engine
ust proof box, one advantage the turbine now has.
echanism. It is also a hardy mechanism, and its
be less than that of any reciprocating engine we

o German conditions, we must remember that
a ton in the Westphalian district and labor and
r there than here, so that the maintenance costs
omparatively lower, and consequently heavier
an be tolerated. I have tried to state these facts
phasizing at the same time that I do not know
sts of repairs of gas engines.

gas installation at works is to be considered from
of view. Mr. Coleman's paper is most valuable
periences. It is a message of cheer to the engi-
o install gas engines. There can be nothing worse
ory of the work of the Lackawanna engineers is
esourcefulness, patience and courage.

that the gas engine, in its present condition, has
at any American steel works. They are now a

fashion. In the discussion of Mr. Freyn's notable paper,[1] Mr. Maccoun sounds a necessary note of caution that "all the conditions should be studied," and later, "in many cases gas-engine installation may be carried too far."

It seems certain that in the present state of the art the steel works located in the cheap coal districts cannot use gas engines economically. It is a question if any of our steel works are now so located that they can. Colorado, Tennessee and the Pittsburg districts all have coal nearly at their doors, while Chicago, Gary, Buffalo, Pennsylvania and Bethlehem are in the debatable region.

The items that now enter into the discussion in the order of their importance are, first, the fixed charges; next the fuel cost and then the operating costs and repairs.

If it is proposed to use gas engines for the purpose of economizing in the generation of electrical power for example, we find almost any steel works plant has a load factor of less than 50 per cent, for the reason that power plants must be built to meet the maximum demand, and when in any such plant, deduction is made for Sundays, holidays and spare engines, there are few working plants that run with a 50 per cent load factor. The Cambria plant runs about 45 per cent, so that 50 per cent or less, is about the load under which the cost of producing current must be considered.

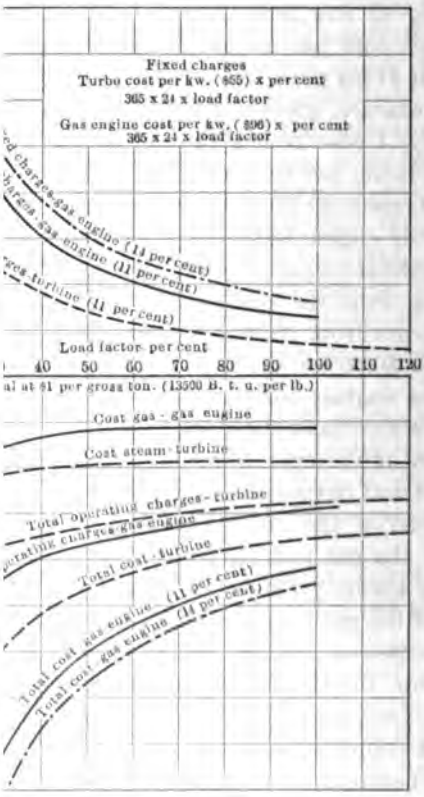
The relative costs of gas-engine and turbine plants are very nearly two to one. A large modern turbine plant including boilers can be built for about $50 or $55 per kilowatt capacity, and a gas-engine plant, including the gas-cleaning apparatus, costs about $96 per kilowatt capacity.

This estimated cost of turbine-generator plant embraces everything from the coal-handling machinery and boilers to the switch board. It has been repeatedly checked and is confirmed in the paper by Mr. Varney and by many other engineers who have built turbo-electric plants. The gas-engine plant is based upon the actual costs of gas engines and other details and is complete from the gas-cleaning plant at the blast furnace to the switch board inclusive. The great difference of cost comes from the fact that one plant has high-speed rotative machinery and the other has slow-speed and necessarily massive reciprocating engines.

It is possible some great advance in the art may change this present condition of relative cost, but considering the present, we have

[1]Trans. Am. Soc. M. E., p. 462.

ı, Fig. 68, representing the approximate and watt-hour as affected by fixed charges, fuel ng costs for labor, material and repairs. Mr. ıper[1] divided these more minutely, but this is ıcussion.



ɔ Relative Costs of Electric Current Produced ɔe Gas Engines versus Steam Turbines

ıe diagram at 50 per cent load factor, the gas ındicap of about $0.001 per kw-hr. for its over the fixed charges of the turbine plant. life, with 11 per cent fixed charges for both ıg to the gas engine, since the chances of obso-

8, p. 1479.

lescence are against the most novel, the most costly and the most complicated machine. It is probable the gas-engine plant should have fixed charges at 14 per cent.

Fuel Cost. This is considered to include the labor and other expenses to make steam in boilers or to wash blast-furnace gas, to serve the steam to the turbine or the gas to the gas engine.

The fuel of five large turbo-electric generating plants averages 2.94 lb. of coal per kw-hr. This covers all auxiliaries. At this rate coal at $1 per gross ton, with the addition of $0.50 per ton to cover all boiler charges, gives a charge for steam at the turbine of $0.197 per kw-hr. Under boilers 318,000 cu. ft. of gas equals a ton of coal at 13,000 B.t.u. per lb. and 95 B.t.u. per cu. ft., and is also valued at $1. It costs $0.75 to clean this gas ready for the engine. Its value at the engine is therefore $1.72, but it will produce twice as much electrical output as a ton of coal. This gives the relative cost of the heat from the coal and gas delivered at the engines as $1.50 for the steam from the ton of coal fired under boilers, and one-half of $1.72 is $0.86 for the heat of combustion of the washed gas when used in the engine; both for the same electrical output.

On the above basis the cost of gas fuel used in a gas engine is about 57 per cent of the cost of steam supplied to a turbine to produce the same electrical output, a saving of 43 per cent in fuel cost. Taking 57 per cent of the above steam cost gives $0.112 as the cost per kw-hr. of the gas fuel for the gas engine. The saving therefore is $0.085 per kw-hr. This is less than the increased fixed charge $0.105 per kw. of the gas engine over the turbine plant.

Other Expenses. These are the engine-room labor for attendance and repairs, the lubricants, waste and repair material. Mr. Stott estimates the charges for maintenance, attendance, repairs, lubricants and supplies for gas engines about three times that for turbo-driven generators, confirming our own experience with reciprocating and turbine plants.

In the five turbine plants before mentioned, the charges for engine-room labor, material and repairs is $0.126 per kw-hr., and the diagram is so drawn for the turbine plant. These charges are doubled for a gas-engine plant, which increases the cost of production and makes the diagram still more unfavorable to gas-engine plants. For these reasons it seems the gas engine cannot now be recommended as an economical appliance in regions of cheap coal, and we should await its further development or a decreased cost per unit.

It is to be understood that the curves in Fig. 68 apply to a plant

v. capacity, where fuel may be obtained at a
or such conditions as obtain at large steel works
ons. If plants of smaller capacity, with smaller
priced coal, should be taken into consideration,
ficiencies and operating expense may vary.

ight be inferred by a person reading this paper
as of necessity a short-lived apparatus without
ndurance, and it is timely, I think, that some
t this impression should be presented.
nstallation is the first of the large installations
ink the next in point of age is the installation
Machine Company at the Edgar Thomson
first engine was put in operation there in 1906.
ing from the officials of the latter company,
not had time to reduce to definite shape, but
e of some interest. The length of service of
ntly long, I believe, to point out what may be

tor cylinders of the Koerting engine are shown
ne piece with water jackets and exhaust passage.
re of cast iron with water jackets, and are pro-
ion joint. Fig. 17 shows a 38½-in. motor cylinder

lief that the cylinder itself is in need of an expan-
ch as is the cylinder head. I doubt the wisdom
t a large gas-engine cylinder integral with its
s a problem of considerable difficulty, and I
y that the possibilities and limitations of the
refully studied at the outset. It is sometimes
to put things on paper that the foundryman
n active service.
linder, the life, as we say, should be the true
n, construction and suitability of material of
e here some dimensions to indicate the small
st in nearly four years' service, when the engines
rned about 98 per cent of the time.
cylinders of this Koerting engine as difficult
t of iron required for obtaining long lifetime,
foundryman's task an easy one.
er in the Westinghouse method of dividing the
to two parts, dividing at the center of the stroke

where the explosive pressure is moderately low, and where there is no difficulty in making a good gas-tight joint. That makes it possible to cast both explosion ends in the "drag," or bottom, of the mold, thus insuring integrity at that part of the cylinder, which has the heaviest stresses to resist.

In Par. 77, mention is made of the cast-iron piston and later in the paper the claim is made that this long piston is good for lubrication in the engine. I think in the first place that good lubrication within this cylinder is conspicuous by its absence in view of the excessive wear which occurred. Furthermore it has been my own observation that a very long piston is bad for the lubrication of any cylinder, whether it is a steam engine or a gas engine. If the packing rings are far apart and well spread, then during the stroke in one direction the leading rings are liable to scrape the cylinder oil ahead of them, leaving the centre of the piston comparatively dry. This is repeated in the opposite direction on the return stroke, so that a long piston may be harder to lubricate than a shorter one.

In Par. 90 mention is made of the method of lubricating the cylinders, and the location of the oil inlets. That matter is one which might not be regarded by persons without previous experience as the most important thing in connection with the lubrication, but in my opinion it is very important. In the Westinghouse engines to which I have referred, the oil is introduced at two points at each working end of the cylinder, and the selection of those two points was very important. An oil hole drilled directly above the piston rod has been found to be in a very disastrous position for oil inlet, for the reason that oil dropping from such a point may fall directly into the flame and in any case not where it would do most good.

The best place for introducing cylinder oil seems to be about 30 deg. on either side of the top centre, and then it will follow down the cylinder wall, being suspended by capillary attraction on the wall of the cylinder, hanging there until it is overtaken by the first packing ring which passes.

It is a little surprising to find the statement in Par. 122 that when the piston in this engine had worn to an amount equal to $\frac{5}{16}$ in. of metal removed from the bottom, it was turned over and used upside down. I presume that the reason this piston wore so much was because it lay on the bottom of the cylinder, acting as an unbalanced slide-valve, so that having contact with the bottom and exposed to extreme pressure on the top, it was pressed down against the bottom of the cylinder wall by the gas pressure within the cylinder, with

n this paragraph it may be deduced that this good.

on engines the pistons are carried on piston carried on cross-head slides, and the pistons at all. They are examined frequently and ouch the cylinder barrels. When I come to g wear I hope you will find they are justifi- r design.

is made of the wear of the piston rods; and tement is made that the wear amounts to $\frac{1}{4}$ years. The investigation as to the amount Thomson engines reveals the following: that n in this engine were made of nickel steel oximately $3\frac{3}{4}$ years, have worn to an amount ear. From my own experience in building he Corliss types, I would say that the life- tically as long as the rods of the steam engine ning practically at the same speed.

is made of the character and lifetime of the particular point my information is not quite nd the time to throw away a piston ring has natter of opinion, but 3 years is given as the in charge of this engine.

cylinders, which of course is a most important ng about the most expensive piece of the ave been taken for the $3\frac{3}{4}$ years in service, by shoulder at each end of the stroke; and in r which was taken as an example, the wear f 0.0055 radially per year. The amount of wear is given as 0.037 maximum and 0.008 f service. That in turn seems to be as good l from the average steam engine running at but with much lower pressures than in the

n of the cylinders in these Edgar Thomson to cast them of low silicon iron and low dense structure of high strength, and the nto two sections they could be fed by very think both of these features are entitled to th of life and the good wearing quality.

aust valves have been replaced. The valves

have been in use from December 1906, until the present time, have never been reground or reseated, and are still tight.

Mr. Morgan has emphasized the item of depreciation in a gas-engine plant and it may be possible to lay more stress on this particular point than the circumstances warrant. At all events, anyone contemplating the installation of a gas-power plant should not be too strongly influenced by the rapid deterioration of these Lackawanna engines. The object in presenting these more favorable statistics of endurance in the case of the Edgar Thomson engines, is for the purpose of affording to any such investigator a more accurate conception of what can be looked for in gas engines of different design and of more recent construction.

GEO. A. ORROK. The Lackawanna plant has a line of blast furnaces, shown in Fig. 1 of the paper. The same drawing shows the engine room, but it does not show what is on the other side of the engine room. On the north side are the Bessemer works. The blast furnaces are about 40 ft. or 50 ft. to the south of the windows on the south side and the Bessemer steel plant is about 60 ft. or 70 ft. from the windows on the north side of the engine room.

On the afternoon on which I visited the plant, four explosions or slips took place, scattering red ore and coke dust. It was in the summer and the windows on the south side were all open and this red ore and coke dust came in and settled over the engines. On the north side there were three 20-ton Bessemer converters working, and the steel dust from those converters was dropping on the engines through the north windows. The pumps were $\frac{1}{2}$ in. deep in steel and ore dust and the edges of the cylinders and the valve parts which moved slowly were covered with $\frac{1}{4}$ in. of dust. Under these conditions I think the engines have done remarkably well, or that any engine did well that ran at all. I believe nine-tenths of the trouble can be laid to the place where the engines are located.

Now compare the Lackawanna works with certain of the plants in Europe. I had the opportunity last summer of visiting four which are perhaps, representative plants. In these works the gas-engine plant is located far enough away from the furnaces to escape dust, and also far enough away from the Bessemer converters. All the windows in the line of flow of the dust are closed and in consequence, the engine rooms are clean. The floor is of tile and it is kept clean and the few oilers are simply engaged in the usual work on the machinery. Dust is absent.

I visited the gas engine plant of the Lackawanna
several occasions and can corroborate what has
)rrok, that the engines had a poor chance, con-
ıding conditions. The troubles they had were in
to design and construction of the engines than to
greatest mistake was, in my judgment, due to
)ut in such a large installation at once; there were
ne men.
speaks a language which must be understood by
rouble is to be anticipated before damage is done,
ınd intimate experience to learn this language.
uble was due to imperfect cleaning of the gas and
remarked, to very unclean air, but probably the
ıge, that is, knocked-out cylinder heads, was due to
ıe composition of the gas. When they first started
blast furnaces and when one of these furnaces had
e percentage of hydrogen became excessive, pre-
e and cylinder heads were knocked out. While
e man understands that water getting into a fur-
ky tuyere is a very bad thing, he appreciates even
the fact that the furnace must be kept in operation.
ıky tuyere was left until flushing or casting time,
; high hydrogen gas, to the detriment of the gas-
ıen the furnacemen became aware of the conse-
tuyeres were at once removed and this trouble very
It was entirely overcome when more blast furnaces
)n. At later visits I was informed that the gas-
ıve no more trouble than steam-blowing engines
rk.

The disadvantageous location of the power and
th respect to the Bessemer converters and the
ıawanna plant, consequently subjecting the gas
severity in operation, due to the floating particles
rved by Mr. Orrok, calls to mind a similar example
king under more or less extraordinary conditions.
Cement Company, Iola, Kan., had in service at
which time an exhaustive report was made on the
ny as 14 four-cycle gas engines (11 verticals and 3
ıjority of the verticals having been installed in 1899.
city then was 4500 b.h.p. and the average length of

service 5.8 years, some engines have been serving as long as 8.2 years. Thirty per cent more power has been added within the last two years by installing two large horizontals. These engines are direct connected to the line shafting, and it is to be noted that the surrounding atmosphere is continually ladened with dust and grit from the crushers and rotary kilns. As a measure of good performance, the outages chargeable to the engines are, on an average, less than 1.6 per cent of the possible operating time. This is very satisfactory indeed when we consider the nature of the service continuing through the 24 hours of the day, and further, on account of the practical preclusion of reserve units attached to each shaft. As the operating force attends to no repairs whatsoever, the maintenance labor is higher than ordinarily obtains in the average power plant. On the basis of $44 per b.h.p. (natural gas engines), the maintenance material amounted to 3.215 per cent of the plant evaluation, and the labor 2.245 per cent, or a total of 5.46 per cent. This may be considered approximately equivalent to an ultimate life of about 18.3 years, which is evidently very satisfactory under the conditions named.

These repairs have been compared with some important steam-engine stations and found to be 30 to 50 per cent less for equal output. It will be remembered that gas engines are generally built, proportionally, more substantial and accessible than the reciprocating steam engine.

Mr. Bole has, in my mind, dwelt upon a very important consideration of gas-engine cylinder structure in emphasising the desirability of dividing the outer wall and providing a jacket band. A valuable contribution[1] on the structural details of gas engines, by R. Drawe of Saarbrucken, Germany, appeared in two of the February 1909 issues of the Stahl and Eisen Journal. The one-piece cylinder design was especially criticized, because of the excessive initial casting strains due to shrinkage difference between the inner and outer walls. Moreover, he expressed the necessity of casting the outer wall in compression and the inner wall in tension in the single-piece design, to counteract operating stresses, which manifestly introduces an extremely uncertain factor owing to the impossibility of properly gaging these stresses. It may be interesting to add that careful tests made in Germany for the determination of the temperature difference of the inner and outer walls, has found this quantity to be in the neighborhood of 75 deg. cent. (167 deg. fahr.), producing stresses in

[1] Stahl und Eisen, February 1909.

ıder many times those due to the explosion pressure
:ylinders were likewise looked upon with disfavor
ifficulty of ensuring tightness of an internal joint
essures which occur in the combustion chamber.
brought out by Mr. Bole, pertaining to the effi-
ient cylinder lubricating system, is well ex-
se of a rather critical test where the 21¾ in. by
ıl engine installed at the Edgar Thomson Steel
as operated 94 hours on gas which was passed
and Grill washers only. The gas was not passed
ien washer at all, and no injury resulted to the
; this time, 2,386,000 cu. ft. of gas was used.
l carried by the gas were collected and amounted
volume, or 47.96 oz., or 3.62 lb. for each end of

interest is attached to the possibility of the large
gines as regards long continuous runs. The record
n. blower at the Bessemer (Pa.) plant of the U. S.
which has come to my attention, covered 45 days
:ary shut-down.
of gas versus steam equipments has been interest-
r. Morgan. There is one feature I desire to bring
n this connection, namely, that the comparisons
:e expenses of gas and steam plants too frequently
repairs, tube replacements and other auxiliary
e steam plant. In the limited opportunity I have
actual data on gas and steam-power machinery,
rdinarily to be only 1¾ to 1 in favor of steam, and it
as 2 to 1.
be carefully considered in weighing any existing
peculiar local conditions, and secondly, the personal
erating force. My opinion on the subject of main-
upon the low or moderate-speed engine. If high
used, I am inclined to believe the repair cost of
nt will increase, as the wear and tear for a given
ars to be some function of the rotative speed.
that the gas engine is considerably handicapped on
it has been established as practical, that the waste
gine may be stored in an accumulator and then used
turbine system to supply the heavy peak loads.
at a low investment cost which would, therefore,
e burden of fixed charges on the gas-engine plant.

G. D. CONLEE. Beginning in the summer of 1905 I worked for two years for the Lackawanna Steel Company under Mr. Coleman. I was there at the time the first satisfactory tests were made on the gas engines and know from experience how carefully these tests were made and what a great amount of work is represented in this paper.

These tests could not have been made had it not been for the theory developed and the experimental work done by Mr. Coleman in the use of the Venturi tube for the measurement of the flow of gases. The theory and results obtained were embodied in a paper read before the Society in 1906 entitled The Flow of Fluids in a Venturi tube.[1]

One question of interest about these engines is the cause for the negative loop on the motor cylinder cards. Referring to Fig. 55, it will be noticed that the diagram from the motor cylinder represented by the dash line has an intersection of the expansion and compression lines.

That is, after the exhaust ports are opened by the motor piston, the pressure in the motor cylinder drops very rapidly so that when the motor crank is about 18 deg. ahead of the dead center, the pressure is about 2.4 lb. below the atmosphere.

The exhaust ports are opened when the motor piston is 39.5 deg. ahead of the dead center, but the scale of the diagrams is so large that this point does not show. The pressure drops rapidly until the low point at about 2.4 lb. below the atmospheric line is reached. The pressure then remains practically constant until the inlet valve opens and admits air and gas, when the pressure rises to 3 lb. above the atmosphere. As the piston starts back the pressure increases to 3.9 lb., then drops back to 2.2 lb., at which point the exhaust ports are closed by the piston and the compression of the charge begins.

The card from the exhaust chamber has a queer shape. It is noticeable that in the middle of the stroke in both directions the pressure changes slightly from above to below the atmospheric line. This is probably due to the exhaust of the other cylinder of the engine which is set at 90 deg. The pressure runs along for some distance slightly below the atmospheric line and then rises almost vertically to fall off gradually until the exhaust ports are opened, when the pressure in the exhaust chamber follows that in the motor cylinder until the piston has begun the return stroke. The pressure

[1] Trans. Am. Soc. M. E., Vol. 28, p. 483.

mber is then about 2 lb. above the atmosphere,
to 3 lb. below the atmosphere at the point where
are closed.
the compression stroke, the pressure in the exhaust
ow the atmospheric line while that in the motor
would indicate that the cause of the partial vacuum
anner to the layout of the exhaust piping and to
f water for cooling the exhaust.
sure diagram was obtained from all of the 2000-h.p.
while the 1000-h.p. higher-speed engines did not
loop.
hat the very low pressure in the motor cylinder at
ening of the inlet valve has a great deal to do with
ough the exhaust ports, and it seems that it might
ilize this principle in the design of plants to good

e condition of the gas as received by the engines and
of the service, it is surprising that these engines
There have been times when a blowing engine has
days without stop.

G. In many instances the results shown in Mr.
are not entirely favorable to the engines, but since
only the first of its size and kind ever constructed,
nposed of engines which were themselves the very
uilt from an original and untried design, it is believed
, Dr. Ernst Koerting, as well as the builders, the
achine Company, may well be proud of their work.
encountered are partly due to errors in the design
nd partly to the fact that the gas itself is not alto-
for gas-engine consumption. Mr. Coleman states
nt time, the amount of dust in the gas varies between
g. per cu. m. Four years ago the conditions were
than this, for at that time the dust content often
200 mg. Fuel of such character cannot fail to be
to any gas engine no matter what may be the char-
. Today the presence of more than 50 mg. of dust
hibitive, and a good modern gas-cleaning plant is
er gas containing not over 20 mg. The amount of
the gas at the Lackawanna plant four years ago is
y the fact that in a four-weeks' run made at that

time, the amount of solid matter which accumulated in the slide-valve housings of the gas pumps of one of the engines was over 10 lb.

The early history of this plant was also marked by great instability in the chemical composition of the gas itself, and during the first few years of operation a sudden rise in the hydrogen content was of common occurrence. This was bound to result in frequent pre-ignitions, and a large proportion of the excessive wear and short life of the working parts was clearly due to the dirty gas and the frequent pre-ignitions.

When supplied with clean gas, the cylinders of a gas engine should be capable of running at least five years without reboring. The De La Vergne Machine Company has calibrated cylinders which had been in continuous service for over five years, and the wear on the same was found to be less than 0.035 in. The cylinder heads will usually outlast the rest of the engine if the cast iron, of which they are constructed, be free from sulphur and phosphorus and the castings are allowed to cool slowly in the molds.

A number of the difficulties referred to, such as the breaking of push rods, faulty ignition and poor regulation, are minor defects due to defective construction. They have been overcome as fast as their existence has become known, since they were not inherent to the system, but were merely questions of design. The most serious defect referred to in Mr. Coleman's paper is the high gas consumption. This is due to the excessive load imposed on the engine by the gas and air pumps, and further to the fact that a very considerable quantity of the gas which sweeps through the cylinder during the latter half of the scavenging period finds its way into the exhaust pipe unburned. In the later designs, the consumption of power by the gas and air pumps has been greatly reduced by fitting them in both cases with automatic poppet valves, consequently greatly reducing the high pressures which formerly existed in the pump cylinders. The lead of the pump crank has also been decreased, reducing the maximum cylinder pressure in the pumps from 10 lb. to 4 lb.

In engines of this type, built by the De La Vergne Machine Company about two years ago, the load due to the pumps was found to be about 12 per cent of the indicated work of the engine cylinders, and in Koerting two-cycle gas engines of European design, the power consumed by the pumps has been reduced to 6 per cent. The high degree of perfection attained in the European models is largely due to the very much greater demand existing abroad for engines of this type. This has permitted the European builders to redesign their product again and again, each time profiting by past experiences.

unburned gases into the exhaust pipe may be
sent instance the trouble may be due to piston leak-
abustion because of insufficient igniter spark, to
gas and air passages permitting the gas to mix
air, or it may be due to the arrangement of the ex-
Assuming that there is no leakage, the arrange-
piping should be most carefully considered. It
the unobstructed flow of the exhaust gases into a
lts in such a momentum, that a vacuum is created
er which draws after it not only the scavenging
of the succeeding charge. The insertion of a
the exhaust pipe would improve this condition
more recent Koerting engines built by the De
Company have a heat consumption of between
3.t.u. per b.h.p-hr. Some of the foreign makers
l designs, guarantee a consumption of not over

n of the fuel charge has been abandoned. Most
oday vary the amount of gas and air entering
the charges delivered into the engine cylinder
e with the load, and also, in like proportion, the
the pumps. This is a great improvement over
ines, in which the energy consumed by the pumps
r all loads. In the more recent designs the regu-
at the engines can be used for cotton mills.
ne Koerting type have been built for a number of
ne European countries, there have been developed
riety of models differing greatly in detail from
hese, the engine built by Messrs. Mather and
, England, shows the greatest departure from the
is remarkable for its simplicity.
rs have, as a rule, abandoned the camshaft, and
nd ignition devices by an eccentric on the main
r also is driven direct from the shaft. The gas
ber, are single-acting with trunk pistons, and
g air pump located between them. The largest
ilt in Europe is of 4000 h.p. with two cylinders,
e cylinder.
are in operation over 200,000 h.p. of Koerting
es, as against 48,000 h.p. in the United States,
the fact that the engine seems to be especially

adapted to this country on account of its reliability and simplicity of design, which permit the cylinders and cylinder heads to be made of cast iron, no matter how large the engine may be. The Koerting two-cycle engine has been regarded with some distrust in steel manufacturing circles in this country since its installation in the Lackawanna works. It should, however, be remembered in this connection that the plant referred to was the first large gas-engine plant ever installed and that, although the difficulties encountered were laid in a large degree to the Koerting engines, they were, in reality, due to untoward circumstances, unsuitable gas and other conditions with which the engines had nothing to do. It should furthermore be remembered that while these first engines were faulty in design in some respects, such errors and the results arising from them can have no real bearing in determining the true value of the Koerting two-cycle principle.

No closure was prepared owing to the death of the author on November 27, 1910.—EDITOR.

No. 1303

NECROLOGY

:PHEN WARNER BALDWIN

phen Warner Baldwin there has passed away
figures in the engineering history of the United
to the era of practical training which brought
d men in the nineteenth century to take part
ients following the Civil War.

winsville, N. Y., February 4, 1833, and received
Homer in that state. He entered the Lawrence
awrence, Mass., as an apprentice under the
dividing his three years between the machine
p and drawing-room. The admiration he felt
d all through his life, and on the death of his
affection and out of sentiment, Mr. Baldwin
om the Hoadley estate a large amount of expert
made a gift to the Society.[1] Mr. Baldwin
lley on his single-valve automatic engines and
n engines. From this experience he always
in the development of agricultural machinery

nager of the Clipper Mowing Machine Works
l was associated with the Johnson Iron Works
. Y., improving the machines of both these
inventions. He soon became one of the promi-
ers in the field of manufacture of steel and was
lding & Jennings Company. But he will be
l as the New York representative and agent for
cessful years for the Pennsylvania Steel Com-
and the Maryland Steel Company of Spar-
remained with these companies until 1904
ut was an honored adviser until his death.

vol. 8, p. 349. Some of this apparatus remains in
iety as museum specimens. Other units have been
y could be made useful.

Mr. Baldwin was intensely interested in the problems of education for the young engineer. When Milton P. Higgins proposed his scheme of half-time schools in which lads were to work at books for half the day and in the shop atmosphere for the other half, Mr. Baldwin's interest was not alone because the projector had been a fellow apprentice at Lawrence, but because he believed the idea to be sound. The Artisan School of Syracuse, in which his friend, Prof. John E. Sweet, is so important a factor, was also near his heart.

Mr. Baldwin was early brought into active relations with the Society. He served on early nominating committees, was made Manager for the term 1887–1890 and Vice-President for 1890–1892. But his greatest service was as Chairman of the Finance Committee with control over the budget of each year. He was successively reappointed fourteen times, and his service ceased only with the changes in Constitution and By-Laws in 1904. He was a member of the Council's committee which bravely faced the problem of the purchase of No. 12 West 31st Street, in 1890, when the Society had no capital to invest in such a great undertaking, but only the earnest purpose of those members whom the Secretary of that date had stimulated to the point of venturesomeness. The bonds issued as a part of the financial scheme were all redeemed and the second mortgage paid off within the period of Mr. Baldwin's activity. He worked very hard for two winters over a plan to develop meetings of the Junior Members of the Society for their common advantage. The monthly meetings of the Society in different cities are a heritage from those efforts.

Mr. Baldwin was a sound and straight thinker, a man of great power of application, an analytical reasoner, a diligent and painstaking worker. Tall and commanding of figure, he had the grace, refinement and broad culture of the scholar. His inventive mind was always at work, adding labor-saving devices as well as improvements to whatever interested him, and his pleasing personality intensified the impression of good fellowship by which he put every one at ease. He inspired such confidence in his integrity that he was constantly sought as an adviser. He was at one time a member of the American Society of Civil Engineers and of the American Institute of Mining Engineers. He was very active also with his friend, J. F. Holloway, in the building up of the Engineers Club, and was one of its four honorary members.

Mr. Baldwin died at the home of his daughter on January 5, 1910, after several years of physical weakness, although of clear mental capacity, and a personality active in the days of the upbuilding of the Society has gone to his reward.

MARK BARY

lied December 27, 1909, was born at Detroit,
873.

his graduation from the University of Mich-
97, Mr. Bary entered the employ of the Michigan
s assistant and later in the same year was en-
man with the Missouri River Company. For
Ir. Bary was employed by Bryan and Humphrey
ical and mechanical work and as superintendent
March 1900, he became engineer-in-charge of the
ıpany at St. Louis, Mo., and later in the same
ıstruction of the city lighting plant of the Imperial
pany, St. Louis. In 1901 Mr. Bary became first
Humphrey, consulting engineer, Detroit, Mich.,
ıg the mechanical design and superintendence
ɛlectrical and mechanical power plants. From
s engaged in consulting practice under his own

ıember of the St. Louis Society of Civil Engineers
ɔciety of St. Louis. He entered the Society in

CHARLES W. BATCHELOR

helor was born in London, December 21, 1845.
parents moved to Manchester, where he received
and where he served his apprenticeship in several
eering works of that city. At the age of twenty-
to this country to install machinery for the Clark
ɔf Newark, N. J., and almost from the first was
d with the inventor Thomas A. Edison, assisting
of the electric pen, the telephone transmitter,
e electric railroad and the Edison incandescent
ystem.

to Europe to represent the Edison interests at the
ibition of that year, and remained in Paris for
ıe was the first to introduce the system of electric
the original installation at the Paris Opera House,
ber of isolated plants in other parts of Europe;
stablishing and managing a large factory at Ivry.
country in 1884, he assumed the management of

the Edison Machine Works, an organization which in the course of time developed into the Edison General Electric Company, and the selection of the site of their large works at Schenectady was made by him. Later this company combined with the Thomson-Houston Electric Company and became the General Electric Company.

Of late years he had practically retired from business and devoted much time to travel, though he retained the presidency of the Taylor & Company Iron Foundry, a concern in which he had been interested since its establishment.

Mr. Batchelor was a member of the Museum of Natural History of New York and the New York Botanical Garden. He was a member for a number of years of the American Geographical Society, the American Institute of Electrical Engineers and the American Electrochemical Society. He entered the Society in 1880.

He died at his residence in New York City on January 1, 1910.

GEORGE HENRY BAUSH

George Henry Baush was born in Holyoke, Mass., April 9, 1870, and was educated in the public schools of that city. His technical training was gained from his father, who founded what is now known as the Baush Machine Tool Company, of Springfield, Mass. In 1896 he became general foreman and superintendent of the Baush Company and in 1904 was elected its vice-president and general superintendent, all designing of machine tools being entirely under his charge. In 1906 Mr. Baush became associated with Hill, Clark and Company of Chicago, as manager of their Philadelphia office, resigning from this position to accept a similar one with the Fay Machine Tool Company of Philadelphia, which he retained until within a few months before his death on September 12, 1910.

CLAY BELSLEY

Clay Belsley died at his home in Peoria, Ill., September 3, 1910. Mr. Belsley was born at Spring Bay, Ill., January 28, 1873, and was graduated from Cornell University in 1898 with the degree of M.E. Soon afterward he entered the employ of the Link-Belt Company of Chicago, where he had charge of the mining machine plants. He later entered the service of the McEntee-Peterson Engineering Company of Peoria, by whom he was placed in full charge of their work in the South, including the building of the electric light plant at Gastonia, N. C. In 1901, Mr. Belsley returned to Peoria and opened a private practice as consulting engineer.

ınt work undertaken at this time, he de-
and power plant for Tom J. Gardner at
alled the mechanical and electrical plant of
nd had charge of the design and construc-
he Woodruff Ice Company of Peoria. He
; this period in expert investigation in con-

accepted the appointment of city engineer
ing his lucrative private practice to per-
While personally superintending the con-
ulvert for the city, he contracted typhoid
lting weakened condition never recovered.

LIAM P. BETTENDORF

f was born in Mendota, Ill., July 1, 1857,
Bettendorf, Iowa, June 3, 1910.
ıic and inventor began with the termination
eship as machinist in the Peru Plow Com-
llowing three or four years were devoted to
ıre of farm implements at Moline and Canton,
ed to Peru, accepting a position as super-
ow Company, and shortly afterward invented
dorf metal wheel, still used in fully ninety
ral implements made in the west. He also
special machinery for the manufacture of
elbarrow wheel to a grain harvester.
ıny being very limited in capital and manu-
Bettendorf organized the Bettendorf Metal
mport, Iowa. With this company he severed
ınd turned his attention to designing an all-
ın wagons. This task, seemingly simple, but
roportions, led him into hydraulics and intri-
its final accomplishment. The gear was
teel pressed into shape by special hydraulic
es, and was the first with a tapering spindle
of standard wooden wagon wheel.
eel wagon gear, it occurred to Mr. Bettendorf
for freight cars could be greatly simplified,
weights reduced and the strength increased.
ines resulted in the Bettendorf brake beam,

pressed from sheet steel similar to the axles of the steel wagon gear. That which will prove an enduring monument to his memory as a car builder is the design of steel underframing for freight cars and the highly advanced methods for its manufacture.

Mr. Bettendorf became a member of the Society in 1895. He was also a member of the Western Railway Club, the New York Railway Club, the Railway Club of Pittsburg, the Eastern Railway Club, the New York Mechanical Club, the American Foundrymen's Association, the Union League Club and the Chicago Athletic Association.

JAMES HENRY BLESSING

James Henry Blessing was born in the village of French's Mills in Albany County, N. Y., September 14, 1837. At his father's death in 1849 he left school and in 1853 was apprenticed to the machinist trade for four years, with the firm of F. and T. Townsend, Albany, N. Y. He remained with this firm until 1861, when he entered the United States Navy as acting assistant engineer. After the war he became engineer in charge of steam machinery of the Brooklyn Horse Railroad Company, returning to Albany in 1868 to act as superintendent of the foundry and machine works of Townsend and Jackson, successors to F. and T. Townsend.

In 1870 Mr. Blessing invented the return steam trap, the best known of his one hundred and twenty inventions. In July 1872 he left the employ of Townsend and Jackson to engage with Genl. Frederick Townsend in the manufacture and sale of these and other steam specialties, under the firm name of Townsend and Blessing. In June 1873, this firm sold their interest to the Albany Steam Trap Company and Mr. Blessing became secretary and treasurer and general superintendent of the company, and afterwards president.

Mr. Blessing was elected mayor of Albany in 1899. He was a member of the Society of Engineers of Eastern New York and of the Albany Historical and Art Society, and entered this Society in 1891. He died in Albany, February 21, 1910.

JONAS HENRY BLOOMBERG

Jonas Henry Bloomberg was born in New York City, February 2, 1870, and was educated in the public schools and later at the College of the City of New York. In 1900 he removed to Mexico where he devoted himself with great success to sugar house machinery. He built and designed most of the modern sugar houses and distilleries

ırtant ones being at the Rio Vista Plantation,
on and the La Crosse Plantation. At the time
', 1910, he was consulting engineer of the Rio
ıpany of Tamasopo, S. L. P.
ı a member of the National Geographical Society

JAMES WELDON BRIDGE

ıdge was born at Atlanta, Ga., March 24, 1873,
e public schools of Atlanta, receiving in 1892
ı M.E. at the Georgia School of Technology.
ɔrience was with the Atlanta Consolidated Street
rom 1894 to 1898, at which time he entered the
Atlanta Railway and Power Company, becoming
ıops in 1900. In 1902 he became superintendent of
ı, Georgia Iron and Coal Company, and afterwards
ns of importance with city and interurban rail-
t the time of his death, December 20, 1909, he
the work of general manager of the Pittsburg,
Vashington Street Railway Company, stationed
a.
ɔd the Society in 1905.

WILLIAM HENRY BRYAN

ɔyan died December 5, 1910, at Chicago, Ill. He
1859, at Washington, Mo., and received his early
ıntry schools. In 1881 he was graduated from
ɨity with the degree of M.E., having spent his
ɔps of the Missouri Pacific Railroad where he
ınd other railroad practices. Since that time he
ıs a general assistant erecting engineer and sales-
Pond; as local manager of the George F. Blake
ıpany, New York; as secretary of the Pond Engi-
nd, in 1889, as secretary and local manager of the
t Company of St. Louis, Mo., then developing a
of incandescent lighting. In 1891 he went to
· of the Western branch of the Yale and Towne
k. Since 1892 he had been a consulting mechan-
ıgineer in St. Louis. During this period he con-
vorks at Washington, Mo., the power plants of
Heat and Power Company, of the Coliseum, of

the Grand Leader, of the Eli Walker Building, and of Ferguson and McKinney, all of St. Louis. He also rendered excellent service in practical smoke abatement for the Citizens' Association of St. Louis in 1892 and 1893.

Mr. Bryan was a member of the Engineers Club of St. Louis, having served as secretary, vice-president and president; of the present Smoke Abatement Committee of the Civic League of St. Louis, of the American Society of Heating and Ventilating Engineers, of the St. Louis Railroad Club, the Mercantile Club, the American Water Works Association, serving on its Committee of Depreciation, and president of the Washington University Association. He became a member of the Society in 1891, and since 1906 had been an active and influential member of the Committee on Meetings, and as such was mainly instrumental in inaugurating and conducting a system of local meetings in St. Louis.

WILLIAM WILBERFORCE CHURCHILL

William Wilberforce Churchill died at Oshkosh, Wis., March 24, 1910. He was born at Monroe, Wis., January 6, 1867, the son of Norman and Dr. Ann Sherman Churchill. After graduation from the Monroe High School in 1883, he spent one year at Rose Polytechnic Institute, and in 1886 entered Cornell University, from which he was graduated in 1889 with the degree of M.E. He was made a Fellow of Sibley College for 1889–1890, and received the degree of M.M.E. in 1890.

After graduation Mr. Churchill spent a few months with E. P. Allis & Company, Milwaukee, Wis., and then entered the employ of Westinghouse, Church, Kerr & Company, New York, where he remained until his retirement because of ill health, in 1906. He rose through various intermediate positions in Chicago, Pittsburg and Boston to be chief mechanical engineer of the company's headquarters in New York, and at the time of his retirement was vice-president and director. During his sixteen years of service he superintended the construction of the Boston terminal; the Kingsbridge power house, New York City; the Atlanta water-power plant, Georgia; the Lackawanna & Wyoming Valley Railroad, Pennsylvania; the Grand Rapids, Grand Haven & Muskegon Railroad; Hotel Pontchartrain, Detroit, Mich.; the Northern Colorado Power Company, Denver, Colo.; the electrification of the Long Island Railroad, New York, and many others. In 1902 he spent some time

tion with the electrification of the London

.

a member of the New York Railroad Club, ty Club, the American Association for the ce, and several Masonic orders.

CHARLES B. CLARK

vas born at Bangor, Me., June 20, 1858, and He was educated in the public schools of began an apprenticeship of five years with Company, Biddeford, Me., during which time l engineering under a private tutor. In 1881 n engineer on a steamboat and in 1882 worked e shops of the Lawrence Machine Company, here he also attended the evening technical bsequently employed as superintendent of con- ery for the Detroit Dry Dock, Detroit, Mich., verson Dry Dock, Port Huron, Mich., and the East Boston, Mass. In 1889 he returned to the ompany as superintendent and general manager, three years later to become manager of the ıy, Orono, Me. Four years later he went to om 1896 to 1898 he acted as manager of the ımpany of Lawrence, Mass. Since February general superintendent of the Eastern Manu- s mills, South Brewer, Me.

EDGAR PARK COLEMAN

ıan was born July 12, 1867, at Decatur, Ill., 27, 1910, at Buffalo, N. Y. His early education country schools and in the Rose Polytechnic te, Ind. In 1893 he was graduated from Leland ersity and two years later from Cornell Univer- of M.M.E. After leaving Cornell he spent one f the Metropolitan West Side Elevated Railroad, ıe seven years following at the South Chicago s Steel Company, making quantitative measure- r, air and gas; efficiency tests of engines, pumps, rs, etc.; and firing boiler trials of hand, stoker, He also originated the design now in use of the i.p. exhaust valve gear; the 8500-i.h.p. exten-

ion release gear for Corliss engines and a steam regulating s... or five pairs of independent and two cross-compound engines on a common receiver. In 1905 Mr. Coleman took up his work of steam engineering with the Lackawanna Steel Company, Buffalo, N. Y., n which he was engaged at the time of his death.

He was a member of the American Chemical Society and the Park Club of Buffalo.

WILLIAM E. CRANE

William E. Crane died on May 22, at Duluth, Minn., after a hort illness. He was born in Burlington, Conn., and received his arly education at the local schools. At fourteen years of age he began to apply himself to engineering and two years later took charge of a small engine at Bristol, Conn. He later went to Waterbury where or twenty-five years he was connected with the Benedict and Burnham Company as chief engineer. After severing his connection with his firm he became consulting engineer for the New England Engineering Company of New York, and designed several power plants of considerable importance, notably, that of the Kings County Electric Light and Power Company, the Passaic Electric Light and Power Company and the Albany and Hudson River Railway Company. Later he was chief engineer at the Hotel Astor in New York City, but ailing health forced him to resign and seek the climate of Minnesota.

Mr. Crane was a member of the National Association of Steam Engineers and joined this Society in 1887. He was the author of a reatise on American Stationary Engineering and had the distinction of being the first man to use the double eccentric on a Corliss engine. In addition to his engineering activities he took a keen nterest in public affairs and contributed much to the press on social conditions.

BARTON CRUIKSHANK

Dr. Barton Cruikshank was drowned in the St. Lawrence River on June 27, 1910, where he was conducting a boys' summer school and camp at Cedar Cliff, N. Y.

Dr. Cruikshank, who was born in Albany, N. Y., February 5, 1866, vas educated in the public schools and Adelphi A... lemy of Brooklyn and in the Brooklyn Polytechnic Institute, ...e he received the legree of B. S.

After graduation he entered the shops of the B... ly Manufacturing Company, in which he soon rose to be superinten... ent and assistant manager, finally becoming president. From there ...e went to Boston

Boston Heating Company, and later to Princeton, graphics and mathematics in the university. In as consulting engineer for the Indurated Fibre ew York, and in 1893 became superintendent of writer Company, Brooklyn. During his residence ık assisted Dr. Larkins in starting and organiz- training high school in Brooklyn.

ed the presidency of the Clarkson School of Tech- N. Y., from which he resigned in 1902 to become ogswell Polytechnic College in San Francisco. returned to the East, entering the employ of the pany in Syracuse, N. Y., as designing engineer, ear prior to his death when he took up the oys' camp which was so unfortunately the scene

CHARLES B. DUDLEY

ıdley died at his home in Altoona, Pa., on Decem- ıs born July 14, 1842, at Oxford, Chenango Co., ived his early education. In 1862 he enlisted as a ıe 114th New York Volunteers and fought in ing a severe wound at the battle of Opequan urning from the war in 1865, he prepared at the d Collegiate Institute to enter Yale, from which the degree of A.B., and of Ph.D. in 1874. His n Lithium and a Glass made with Lithium was stract in the Proceedings of the American Asso- ncement of Science.

r he became assistant to Dr. George F. Barker, at the University of Pennsylvania, and during in the Franklin Institute Journal some transla- hnical papers. After a month spent as teacher view Military Academy, Poughkeepsie, N. Y. r 1875 to Altoona to take up what proved to be ist of the Pennsylvania Railroad.

entered upon his new task, no railroad had a mployee, although many hadhad occasional chem- he whole subject of the relation between scientific ractical use by railroads was in a very chaotic be possible to enumerate the special investiga- ding to modifications of practices in daily use on been considered since that time by the experi-

mental department at Altoona, for the chemical [illegible] Dudley was responsible. That which attracted the most widespread attention, perhaps, was the study of steel rails, made in the early eighties, which gave the steel-maker as never before a view of his product from the standpoint of the consumer and forced upon him a study of it not only for immediate output but also with a view to the demands which service would make upon it.

Another very important line of work, perhaps the most exacting and time-consuming undertaken, was the making of specifications. Investigations were made, furthermore, into the questions of ventilation, car lighting, steam heating of cars, disinfectants, cast iron for car wheels and other important uses, paints, long-continued tests on bearing metals, analyses of coals, water supplied both for boiler use and drinking, and explosives.

Dr. Dudley had been abroad on three important commissions: in 1886 to study oil burning on locomotives in Russia, in 1900 as a delegate to the International Railway Congress in France, and in 1909 as a delegate to the Convention of the International Society for Testing Materials in Denmark. He had been vice-president of the American Institute of Mining Engineers, and twice president of the American Chemical Society. At the time of his death he was president of the International Society for Testing Materials, as well as of the Bureau of Explosives of the American Railway Association. He was a member of the English, French and German Chemical Societies; of the Iron and Steel Institute of Great Britain; of the Verein deutscher Eisenhüttenleute; the American Society of Civil Engineers; the American Institute of Electrical Engineers; and social clubs in Philadelphia, Washington and New York. He was also much interested in the Altoona Mechanists' Library.

Dr. Dudley was a member of the Research Committee of the Society at the time of his death.

JOHN DENISON EVARTS DUNCAN

John Denison Evarts Duncan was born at Union Falls, N. Y., July 26, 1871. His preparation for his university course was in the high school of Ann Arbor, Mich., and in 1893 he was graduated from the University of Michigan with the degree of B.S. in electrical engineering and in 1894 from Cornell University with the degree of M.E. From 1894 to 1896 Mr. Duncan was employed by the Terre Haute Street Railway Company, Terre Haute, Ind., and the Stanley Electric Manufacturing Company, Pittsfield, Mass. With the latter

ssociated with Mr. Stanley and Mr. Chesney in
perimental work connected with the solving of the
problems which were first studied and worked out
On leaving the Stanley Electric Manufacturing
ıncan successively held positions in New York with
Street Railway Company; the Western Electric
lew York Telephone Company; Westinghouse,
Company; and the Consolidated Railway Electric
ipment Company. In 1901 Mr. Duncan entered
lerson and Porter, New York, and in 1903 was sent
H., by his firm to construct a 1000-kw. power sta-
ıgham County Light and Power Company. At the
July 13, 1910, he held the position of managing engi-
ıe firm. While directing the engineering work of
ıcan was in responsible charge of the design and
large and diversified projects and well earned the
onfidence of his employers, associates and friends
business circles. All who knew him and his work
satility, sound judgment and exceptional ability.
s a member of the American Institute of Electrical
oklyn Engineers Club, the Engineers Club of New
ery Club of the City of New York, the Michigan
ς, the University of Michigan Club, and the Cor-
ıb of New York.

RALPH WALDO EMERSON

merson was born at Orland, Me., March 18, 1872,
early education at the country schools and the
ıcademy. In 1890 he entered the Worcester Poly-
where he received his technical training, leaving
ore graduation, to serve an apprenticeship with
e Manufacturing Company, of Providence, R. I.
or two years and was subsequently connected with
ine Company and the Norton Emery Wheel Com-
Mass. In 1898 Mr. Emerson accepted a position
the Cereal Machine Company of Worcester, Mass.,
Shredded Wheat Company and was responsible
ecial machinery. When the company moved to
ook charge of the layout and equipment of the
he position of draftsman rose to that of mechan-
1904 he became master mechanic of the Case

Factory of the Singer Manufacturing Company, South Bend, Ind., with which company Mr. Emerson was connected until some six months before his death, when, as mechanical engineer and factory economist, he opened an office of his own.

In coöperation with Frank Bishop, Mr. Emerson invented and patented a refrigerating machine for domestic use.

Mr. Emerson was a member of the Commercial-Athletic Club of South Bend.

JAMES B. FAULKS, JR.

James B. Faulks, Jr., was born December 13, 1873, at East Orange, N. J. After his early education in the public schools, he attended the Bordentown Military Institute and later entered Stevens Institute of Technology from which he was graduated in 1896 with the degree of M.E. He held during his lifetime many positions of prominence in engineering work, among which may be mentioned that of draftsman with the Standard Air Brake Company of New York, of engineer of tests with the Edison Electric Illuminating Company, New York, of designer with the Harrisburg Foundry and Machine Works, Harrisburg, Pa., and also with the Crocker-Wheeler Company, Ampere, N. J., and of mechanical engineer with the New York Safety Steam Power Company, New York. He was also prominent in connection with experimental work on the Roumaine cultivator, and was identified with research work in gas engines. In 1904 Mr. Faulks accepted a position at Syracuse University as an instructor in the L. C. Smith College of Applied Science, and at the time of his death, July 14, 1910, occupied the chair of experimental engineering.

Professor Faulks was a member of the Technology Club of Syracuse.

CHARLES A. FERRY

Charles A. Ferry died at Phoenix, Arizona, May 2, 1910. He was born at Utica, N. Y., September 1, 1851 and prepared for college at the Montreal High School. After a year at McGill College he entered Yale from which he was graduated in 1872 with the degree of A.B. He remained in New Haven for three years doing graduate work and in 1875 went to Chicago where he studied law in the office of Judge Upton. Shortly afterwards he became interested in manufacturing and was engaged in the manufacture of steel railway couplers, in 1891 becoming president of the Chicago Tire and Spring Company. For several years before his death Mr. Ferry was not engaged in active business, but was always interested in the

ience of modern times as applied in all direc-

RLES FREDERICK FOSTER

ster was born in Boston, Mass., September 28,
d in the public schools of Boston and the Pun-
ndover, Mass., from which he was graduated
seventeen he began his engineering career as
leveler and transitman, in the office of the City
iere he remained until 1872. The next three
the Lowell and Andover Railroad and in the
ence, Mass. Subsequent to this he became
r McConnell in general engineering in and
rom 1876 to 1880 occupied the position of
nd superintendent of the St. Louis Cotton
. In 1873 he became assistant engineer of
er Company, St. Louis, Mo. In 1893 Mr.
with the World's Columbian Exposition at
ue to his excellent work and energy that the
as completed in time and the fair opened on
also connected with the International Expo-
as mechanical and electrical engineer and
position at St. Louis, Mo., held in 1904, as
er.
l to Chicago and resumed his private prac-
e time to the compilation of engineering data
is sudden death on May 8 left unfinished.
mber of the Western Society of Engineers and
St. Louis. He became a member of this

y of Engineers records in its minutes: "Mr.
nembered for his wonderful power of thought
mitable energy; his deductive mind; his mas-
rtive ability; his skill in handling large bodies
them into a concrete, harmonious, forceful
ection with various universal expositions; and
s lovable character and amiable disposition."

JOSEPH GARBETT

o was for many years prominently identified
ndustry of Minneapolis, died at his home in

that city, August 22, 1910. He was born in Shropshire, England, January 7, 1852, in which county he received his early education, and where he spent the first years of his commercial life in the Horsehay Iron Works, and later was associated with the Coalbrookdale Iron Works, becoming superintendent of the latter at the age of twenty-three. In 1879 he left England and entered the employ of O. A. Pray and Company, Minneapolis, manufacturers of flour and saw-mill machinery, as foreman and pattern-maker. He steadily developed into a thorough and able mechanic and when the Twin City Iron Works was established he, with O. P. Briggs, constituted the firm, Mr. Garbett serving as chief engineer. It was here that he designed the Twin City Corliss engine which is so favorably known throughout the country today. When the Twin City Iron Works was absorbed by the Minneapolis Steel Machinery Company in 1902, Mr. Garbett was prominent in its affairs, becoming mechanical engineer of that company as well as a director.

In steam engineering Mr. Garbett was an accepted authority. For the past five years he had devoted much time to gas engines and gas producers. He spent several years abroad studying the various types of foreign power plants of this type, and finally adopted the Muenzel, a German engine, as the foundation of a gas engine for American manufacture. To this he applied his skill and engineering ability and developed one of the most successful gas engines and suction producers in use in this country today.

ALFRED MONTGOMERY GOODALE

Alfred Montgomery Goodale died in Waltham, Mass., December 17, 1909.

He was born in Saco, Me., December 20, 1855, and educated in the public schools of that State, receiving from the Maine State College the degree of B.S., in 1875. He served for five years in the works of the Saco Water Power Machine Shop, Biddeford, Me., and the Bates Mills, Lewiston, Me., building, setting up and running cotton machinery; and in 1880 became superintendent of the Newton Mills, at Newton Upper Falls, Mass., afterwards acting as agent, from 1881 to 1883, and from 1884 to 1894, for the Hamilton Woolen Company of Amesbury, Mass., and the Boston Manufacturing Company, of Waltham, Mass. Since 1894 he had been treasurer and a director of the Boston Manufacturing Company. With each of these companies, Mr. Goodale had charge of the erection of new machinery, engines and

reorganization and improvements of the existing started the firm of A. M. Goodale and Company, n cloths and yarns.
ed on various city commissions and was a trustee pital. He was a director of the New England and tment Company and of the Westfield Creel Com- lub and Masonic connections he was president of otton Manufacturers' Association. In 1898–1901 y, which he joined in 1886, as one of its Managers.

FREDERICK BELLOWS HALL

ws Hall was born October 18, 1868, at Boston, d his technical education at the Massachusetts logy and after graduation in 1890, was employed now known as the Boston Elevated Street Rail- draftsman on the design of their Central Power wing year, as chief draftsman with F. S. Pearson, r, Boston, he designed various power stations, ooklyn City Railroad Company, Brooklyn, N. Y., ailway Company, Montreal and Quebec, St. Johns mpany, St. Johns, N. B., Halifax Street Railway pany, Halifax, N. S., Chelsea Gas Lighting Com- ass., Charlestown Gas Company, Boston, Mass., ghting Company, Brighton, Mass. During this d as superintendent of construction of power altimore Electric Refining Company, Baltimore, ng and Power Company, Dover, N. H., and the ailway Company, Portland, Me. He was sub- d as assistant chief engineer of the Brooklyn City Rapid Transit) Company in charge of the design of their Kent Avenue, Southern and Ridgewood d in 1894 had charge of the design and construction tation of the Consolidated Traction Company (now Corporation of New Jersey), Newark, N. J. In the design of apparatus for the manufacture of d in the following year was employed by J. H. lting engineer in charge of the design of a power inway Railway Company at Astoria, New York. e became treasurer and general manager of the ing and Transportation Company, Sydney, Cape

Breton, N. S., leaving there to become chief draftsman for the Riter-Conley Manufacturing Company of Pittsburg in charge of the design of blast furnace and steel works for the Dominion Iron and Steel Company of Cape Breton. From 1899 to 1901 he was engaged on the design and construction of the main power station of the Manhattan Elevated Railway Company, New York City, and at the time of his death, October 27, 1910, was in the employ of W. E. Baker and Company of New York.

HARRY S. HASKINS

Harry S. Haskins died at his home in Philadelphia on March 13, 1910. Mr. Haskins was born in Moretown, Vt., March 5, 1834, and at the age of twelve entered the machinists' trade, first with Edwin Harrington and later with the Junction Shop, both in Worcester, Mass., where his family had moved. When Mr. Harrington went to Philadelphia, to engage in the building of machine tools, Mr. Haskins accompanied him, and soon afterwards the partnership of Harrington and Haskins was formed, which later became the firm of Edwin Harrington, Sons and Company. On the death of Mr. Harrington, the business became incorporated, with Mr. Haskins as president, an office which he retained until the time of his retirement, in 1900. Through his mechanical ability and inventive faculty he added many improvements to the gear-cutting machines, hoists and overhanging railways manufactured by the firm.

GUSTAVUS C. HENNING

Gustavus Charles Henning, one of the foremost experts in the testing of steel and an inventor of testing apparatus, died at his home in New York City on December 30, 1910.

Mr. Henning was born in Brooklyn in 1855, and educated at the Polytechnic Institute of Brooklyn and at Stevens Institute of Technology from which he was graduated in 1876 and where during his college course he was fortunate enough to come under the influence of Prof. Robert H. Thurston.

Immediately after graduation he entered upon the work of inspection of steel for engineering structures. This work brought him in touch with the late George S. Morison and made him familiar with the problems of structural material.

His inventive genius and the opportunities for its exercise resulted in the design of a form of extensometer which he described in two

Society, A Mirror Extensometer[1] and A Roller
is study of the defects and limitations of the high-
achines operated on the usual hydraulic principle
gn of a testing machine for full size specimens in
f the adjusting screws is the measure of the stresses
imen. The two screws, or more, should be fitted
xtensometers and their uniform stretch within the
material would be a constant measure of the effort
ference from friction inertia and other causes.
as a great admirer of the Emery design of testing
s sent abroad as a representative of the manufac-
allation of certain important British and German
ances which he made during this sojourn resulted
as the official delegate and representative of the
conferences of the International Society for Testing
as during this time that Mr. Henning made very
butions to professional literature in the form of
on Standardization of Methods of Testing, which
Transactions, Vols. 6, 11, 12, 14, 17, 18 and 20.
Mr. Henning's labors at this period caused a break-
rom which it is fair to say that he never fully re-

ion of the American Society for Testing Materials,
und himself rather in the insurgent class as the
eriences and opinions formed during his professional
reason he took no part in the formation of the stand-
s and attacked them vigorously when presented
y. Business changes and the development of special
capacity for the conduct of the work of inspection
aterial resulted in Mr. Henning's abandonment of
k in that particular field.
of his life during the continuance of a state of health
l his attention to business, were devoted to develop-
e diamond as a cutting face for tools. He found con-
pment for this special work in the manufacture of
in hard rubber. He presented a paper before the
thly meeting in December 1904, elaborating in some
l achievements in this field.[3]

[1] M.E., vol. 18, p. 849.
[2] M.E., vol. 23, p. 594.
[3] M.E., vol. 26, p. 409.

Mr. Henning became a member of this Society in 1880. He was also a member of the International Association for Testing Materials, the Iron and Steel Institute of Great Britain, the Iron and Steel Institute of America, the American Society for the Advancement of Science, the American Geographical Society, and the American Institute of Mining Engineers. His other contributions to the Society were Notes on Steel,[1] On the Elastic Curve and Treatment of Structural Steel,[2] and Investigations of Boiler Explosions.[3]

LEWIS JOHNSON

Lewis Johnson, one of the oldest members of the Society, was born in New Orleans, La., June 8, 1836, and was educated in private schools. Following a natural tendency for mechanics he entered the mechanical profession while very young and served both at shop practice and marine engineering. His education was gained by close and earnest study and by a wide experience which included, among other things, the designing and constructing of new machinery for the baling of cotton, ginning of moss, manufacture of ice, and propulsion of steamers. During the last few years of his useful life, Mr. Johnson was president and chairman of the Executive Committee of the Sewerage and Water Board of New Orleans, and of the Audubon Park Association, both directed toward civic improvement. At the time of his death, May 26, 1910, he was president of the Johnson Iron Works of New Orleans.

WASHINGTON JONES

Washington Jones, who died on July 30, 1910, was born in Philadelphia, February 22, 1822, and became an apprentice at the works of Merrick and Agnew at fifteen years of age—the first apprenticeship taken in that establishment, it is said. His industry and capacity were attested by his advancement to positions of responsibility there and in several other engineering works of Philadelphia, such as the Southwark Foundry, Merrick and Towne, and the Penn Treaty Works of the Neafie and Levy Ship and Engine Building Company. He was associated with the Port Richmond Iron Works of the I. P. Morris Company as constructing engineer from 1856 to 1891, with a brief interruption of a few years at the Southwark Foundry, when he bore

[1] Trans. Am.Soc.M.E., vol. 4, p. 410.
[2] Trans. Am.Soc.M.E., vol. 13, p. 572.
[3] Trans. Am.Soc.M.E., vol. 20, p. 649.

't in the productions of that establishment during

been a member of the Society since 1880. He was
member and past-president of the Engineers Club
member of the American Society of Civil Engineers,
viving member of the Franklin Institute, of which
dent at the time of his death.

WALTER CRAIG KERR

Kerr was a notable example of a type of engineering
iar to the United States, the producer of great engi-
ients, who is a constructor as well as a consulting
n engineer draws up and submits to his clients his
s for the work to be done for the latter; and then as
ieral contractor undertakes to carry these out under
ı, his compensation coming to him not in the form
s fee, but of the profits from the financial under-
stem has been called the American system as dis-
the British or European.

born at St. Peter, Minn., on November 6, 1856. He
rom Cornell University in 1879 with the degree of
emained at Cornell for an interval of three years, as
later assistant professor in mathematics. In 1882
lesman and installing engineer for the Westinghouse
ıny, East Pittsburg, Pa., designing the general instal-
ompany. In the following year he was made manager
office. Through his realization of the common advan-
r and consumer if the former can both supply the
roperly erect it, a company was formed in 1884 of
Westinghouse, William L. Church and W. C. Kerr
us. In this company and with the work it soon
f to do, Mr. Kerr was a forceful personality; and
organization and his energy as an officer have been
the increase of its scope and the magnitude of its under-
as vice-president at the start and, as the result of
the personnel, he was president of the company at the
h. He was at one time vice-president of the Westing-
Company, was also a director of the Electric Properties
s death and had recently been elected a vice-president
ts' Association by New York City merchants. He be-
of the Society in 1886 and was active on its commit-

tees whenever asked to serve and full of helpful suggestions at many times. He was a member also of the Engineers Club, the American Institute of Electrical Engineers, the Canadian Society of Civil Engineers, and other business and social organizations. He was an enthusiastic yachtsman at his home on Staten Island and governor of the local club. He died at Rochester, Minn., May 8, 1910.

It results of course from Mr. Kerr's advocacy of the constructive principle above referred to, that coöperation of engineer and contractor is to be preferred to an antagonism between them, that his monuments of achievement are those of his company rather than of any individual. This is both a loss and a gain, or perhaps is the algebraic sum of the two. By embodying their own designs in a materially existing structure, the name of the designs is not lost, as is so sure to be the case when they do not also construct. The grandeur of the structure as a material fact overshadows the mental achievement of the great concept, and the fact that it was the work of many obliterates the significance of the work of the organizing mind. But the work of the company has covered the construction of interurban electric lines in Michigan, Ohio, Missouri and New York states; power plant design and installation using both steam and water power for railways, lighting plants and producing factories. This firm electrified the Long Island Railway among others. Much of the power and hydroelectric plant for Cornell University was put in by their company, as Mr. Kerr had served as Trustee for the University for many years and was active in bringing Prof. R. H. Thurston to the Directorship of Sibley College in 1885.

But the most considerable single undertakings with which Mr. Kerr will always be identified were the engineering of the great Southern Terminal Station in Boston, Mass., and the great uptown terminal of the Pennsylvania Railroad at the end of its tunnels under the Hudson river, and the connecting subways in New York City. These are splendid examples of the effective coöperation of the architects and engineers of the railways as owners and beneficiaries, and the consulting-constructing parties who were grouped together under Mr. Kerr's leadership. The Pennsylvania Terminal at 33d Street and 7th Avenue was visited by the Society in a body under the guidance of Mr. Kerr and Mr. Gibbs, by their invitation, at the time of the Annual Meeting in New York in 1909. Mr. Kerr was persuaded to present an account of the Boston Terminal at the Annual Meeting of the Society in December 1899[1] which is a model of the clear and concise presentation of a large topic.

[1]Trans. Am.Soc.M.E., vol. 21, p. 451.

JOHN EDWARDS McKAY

McKay was born February 22, 1837 in New York
. his early education in the public schools and in the
ow the College of the City of New York. In 1852
ears apprenticeship with Charles W. Copeland of
n 1854 entered the drawing-room of the Morgan
York, as draftsman and machinist. In May 1859
third assistant engineer, U.S.N., from which post he
ving one year, and was again employed by Cope-
Coast Survey. In August 1862 he was reappointed
de in the Navy, in December promoted to second
1 May 1864 made first assistant, retaining this
years. At that time men in the service of the
tical experience as well as ability to design and
were much in demand, and as Mr. McKay was well
e respects he was ordered to shore duty at Washing-
e under the direction of Benjamin F. Isherwood,
au of Steam Engineering, he made designs and draw-
gines, boilers, etc., for many of the government war-
68 to 1872 Mr. McKay was superintendent of the
. Engine Company, Utica, N. Y., designing and con-
steam engines, rolling-mills, saw-mills, etc. He in-
ime a very excellent automatic variable cutting-off
es.

request of Mr. Tracey, chief engineer of the Croton
McKay severed his connection with the Wood and
and entered upon a public service career. During
dating from 1872 until his death on May 12, 1910,
connected successively with the Departments of
Water Supply, and of Water Supply, Gas and Elec-
York City, and was prominently identified with the
improvements and extensions in connection with
y of the Boroughs of Manhattan and the Bronx,
called, and with the care and maintenance of the

ie work done by Mr. McKay were one design and
the construction of the tower, chambers, gates,
te., in connection with the storage reservoir on the
he Croton River at Boyds Corners, Putnam County,
n and preparation of the plans for the storage reser-

voir on the middle branch of the Croton River near Brewster's Station, Putnam County, N. Y.; the design and drawing of the junction gate-houses and appurtenances, at 113th Street and Amsterdam Avenue and at 93d Street near Columbus Avenue, New York City, and the drawings of the six lines of four-foot pipes between these gate-houses for the replacement of the old aqueduct between those points; the design and drawings of the first successful submarine pipe between Manhattan and Blackwells Islands for a supply of Croton water to the institutions on the latter; the design and drawings and superintendence of the installation of the five-million gallon pumping engine now in the High Bridge Pumping Station, and also the superintendence of the six-million gallon pumping engine in that station; the original studies and plans of the High Service Pumping Station, machinery, boilers, stand-pipe and tank, etc., between 97th and 98th streets near Columbus Avenue, New York City; the design and drawings and the superintendence of installation of a specially designed quick-action 36-inch valve in the gate-house of the Central Park reservoir for the control of a fire line to the lower part of Manhattan; drawings in connection with the Fourth Avenue improvement work from 42d Street to the Harlem River and the supervision of construction on this work. From 1903 until the time of his death Mr. McKay had responsible charge of the Croton, the Bronx and the Byram water sheds and the storage reservoirs there, including the dams, gate-houses, aqueducts, pipelines and appurtenances and the distributing reservoirs in New York City, and was responsible for the proper conservation of the storage and the flow through the aqueducts to the city.

Mr. McKay was a member of the American Society of Civil Engineers and the Engineers Club, and at the time of his death resided in White Plains, N. Y.

JAMES D. MACPHERSON

James D. Macpherson was born in Glasgow, September 15, 1872. He was educated in the public schools of his native city, and there served his apprenticeship in the machine shop, later going into the drafting room of Lees and Anderson, builders of marine engines.

After a cruise on a tramp steamer, as assistant engineer, he came to the United States in 1891, entering the service of the James Leffel Company, builders of turbines and water wheels, first in New York and later in their shops at Springfield, Ohio. While there he was

tant in the designs for the great turbine plant of the
wer Company and other work of similar character,
.898. He then entered the employ of the Diesel
of America, Providence, R. I., as chief draftsman
gineer.
ling and home study he had added much theoretical
s practical experience, and under the guidance of
er, Arthur J. Frith, he mastered the elements of
and of electrical science. During 1901 he was
ing and improving the details of construction of the
n 1902 he was chief designer for Diesel engine work
and British Manufacturing Company of Providence,

1903 until his death he was in the employ of the
Engine Company, New York, first as assistant, and
gineer.
son died at Paterson, N. J., on November 9, 1910.
of sterling integrity and loyalty, a careful and con-
er; and the mechanical success of the American type
is in large measure due to him.
nber of the Engineers Club of St. Louis.

WILLIAM METCALF

alf was born at Pittsburg, Pa., September 3, 1838, and
ere and at the Rensselaer Polytechnic Institute, from
aduated in 1858. Immediately after graduation he
ploy of the Fort Pitt Foundry, as draftsman and after-
tendent, and later joint proprietor. One of his chief
tendent was the casting of mortars, shells and guns
tates Government during the Civil War, at a time
cast-iron guns ever made were being cast at this

e close of the war, Mr. Metcalf bought an interest
iller, Barr & Parkin, later Miller, Metcalf & Parkin,
ration in 1889 known as the Crescent Steel Company.
engaged in the manufacture of fine steel. In 1895,
ired from the Crescent Steel Company and in 1897
raeburn Steel Company, of which he was principal
president at the time of his death, December 5,
, Steel, a Manual for Steel Users, is regarded as an

Mr. Metcalf was a member and one-time president of the American Society of Civil Engineers and the American Institute of Mining Engineers, and was the first president of the Engineers Society of Western Pennsylvania. He had served as vice-president of the American Iron and Steel Association, and was a member of the Institution of Civil Engineers of Great Britain. In addition he was a member of the Duquesne Club of Pittsburg, the Century Association and Engineers Club of New York, and was actively engaged in hospital and charity work. He was appointed by the United States Government one of seven appraisers for the condemnation of the property and franchise of the Monongahela Navigation Company, in March 1897.

Mr. Metcalf entered the Society in 1880 and served it as a Vice-President from 1882 to 1884.

WILLIAM NELSON PARSONS

William Nelson Parsons was born at Northampton, Mass., February 15, 1869, and received his technical training as a special student in mechanical engineering at Cornell University.

Mr. Parsons served his apprenticeship as a machinist with Charles C. Herrick of Northampton and later entered the employ of the Deane Steam Pump Company, Holyoke, Mass., and the Stanley Electric Manufacturing Company, Pittsfield, Mass. In 1900 he was employed in the drawing room of the Taft Pierce Company of Woonsocket, R. I., and at various times subsequently with the Goulds Manufacturing Company of Seneca Falls, N. Y., the Royal Electric Company of Montreal and the Steamobile Company of America, Keene, N. H. At the time of his death, April 24, 1910, he was chief draftsman for the Buffalo Bolt Company of North Tonawanda, N. Y.

WALTER L. PIERCE

Walter L. Pierce was born at Boston, Mass., June 8, 1855, and was educated at the public schools of Boston and New York. In 1878 he entered the employ of the Lidgerwood Manufacturing Company, New York City, as a stenographer and, while holding this position acquired his technical training through private tutors from Stevens Institute. Mr. Pierce was connected with the Lidgerwood Manufacturing Company for thirty-two years, during twenty-nine of which he acted as its secretary and general manager. He died in New York City, December 10, 1910.

s remarkable as an organizer and so perfect was his
tail of the great business that grew up under his
ted during his long absences from his desk while
Besides his connection with the Lidgerwood Manu-
ny he was treasurer of the Hayward Company and
l Lidgerwood Manufacturing Company, both of New
member of the Engineers Club, the Machinery Club,
s a director, a past-president of the National Metal
ion, and an associate member of the Society of
s and Marine Engineers.

FRANCIS JOHN PLUMMER

Plummer of Norwich, Conn., died April 5, 1910, and
Worcester, Mass.

was born at Lancaster, Mass., February 29, 1840.
iced from 1857 to 1860 to Ball & Williams of Wor-
nd continued with them as journeyman machinist
sequently becoming foreman and superintendent for
s and R. Ball & Company, where he remained until
entered the employ of the S. A. Woods Machine
oston, leaving them for a brief connection as partner
E. C. Taintor & Company, of Philadelphia. Return-
ton firm, he took charge of the works and acted as
from 1878 to 1885. His next connection was with
ters of Philadelphia, also builders of wood-working
ere he held for five years the position of designer of
achinery. In 1890 he became associated with C. B.
pany of Norwich, Conn., of which he was superinten-
ger until 1907, when ill health compelled his resigna-
was almost exclusively the design and manufacture
g machinery, especially planing, molding and sawing
eneral building and car work. Many of his inven-
extensively manufactured by the American Wood-
inery Company.

was a member of Sedgwick Post, G. A. R., having
Worcester with the Third Batallion Rifles in April 1861;
masonic orders. He entered this Society in 1891.

CHARLES T. PORTER

ot Porter, a charter member of the Society and
e John Fritz Medal for his "work in advancing the

knowledge of steam engineering and for improvements in engine construction," died in New York, August 28, 1910, at the home of his son, Louis Morgan Porter.

Mr. Porter was born at Auburn, N. Y., January 18, 1826. He was descended from a notable line of New England ancestors including, on his father's side, the Rev. Jonathan Edwards, and on his mother's side, Governor John Winthrop of Massachusetts and Governors Saltonstall and Winthrop of Connecticut. He was graduated from Hamilton College in 1845 and at the fiftieth reunion of the class presented the Half-Century Annalist's Letter, a feature of the annual meetings of the Hamilton alumni. After graduation he read law in his father's office in Auburn, and was admitted to the bar in 1847. The next year he married Harriette S. Morgan of Aurora, N. Y., and their married life was unbroken until within a few weeks of Mr. Porter's death, when Mrs. Porter died.

After practising his profession for six or seven years, first at Rochester and afterwards in New York City, Mr. Porter became interested in mechanics in connection with a stone-dressing machine invented by one of his clients, which failed to operate satisfactorily. Believing that the fundamental principles of the machine were correct Mr. Porter went to work to improve it, picking up by the way a knowledge of drafting and designing, and therein brought out his latent mechanical ability. The stone-dressing machine was driven by a steam engine which he desired to run at high speed, but the governor was of the usual simple fly-ball type which could not be speeded up and consequently the regulation of the engine was faulty. To remedy this defect Mr. Porter was led to design and perfect his well-known central counterpoise type of governor which has since carried his name.

Subsequently came the development of the high-speed Allen steam engine, later known as the Porter-Allen engine, which was essentially the life-work of Mr. Porter. The first engine was built in this country and shown at the London Exhibition of 1862, equipped with the Porter governor, and operating non-condensing. In 1867 at the French Exposition five engines were installed, the only high-speed engines exhibited.

The exhibit at London and subsequent attempts to sell engines of this type in England showed the demand to be entirely for condensing engines. This brought about the development by Mr. Porter of a jet condenser to be direct-connected to his engines, with an air pump adapted to the high speed at which the engines ran. The building of these engines was begun in England in 1864.

. steam engineering Mr. Porter became associated
uainted with many of the early distinguished engi-
th John F. Allen and Charles B. Richards. Mr. Allen
ink and valve motion for steam engines, well adapted
Porter counterpoise governor, and it was the com-
Porter of this mechanism with his governor, together
s advanced ideas upon high rotative speeds and meth-
nstruction, that resulted in the Porter-Allen engine.
e study of steam economy was the need of a steam-
adapted to high speeds. This led to the design by
the first indicator to meet these requirements. The
quired by Mr. Porter and an instrument was shown
vith the engine at the London Exhibition. It was
ds manufactured by Elliott Brothers of London.
nanufacture of his engines, many practical difficulties
owing to the crudeness of machine shop methods.
ces and systems of manufacturer were introduced
to attain the accuracy, without which successful
hinery would be impossible.
Porter returned from England, formed a partnership
and began the manufacture of engines in a small shop
Y. During the three years of business depression, be-
873, the manufacture of the engines was discontinued,
egun at the Hewes and Phillips Iron Works at Newark,
Ir. Porter's own name. They have since been manu-
e Southwark Foundry and Machine Company at Phila-

Porter installed a high-speed steam engine in the Edi-
at Menlo Park, N. J., which marked the beginning of
ed generators. Following this, the first of a series of
called steam dynamos was constructed for the Edison
rl Street, New York, each independently driven by a
engine.
events are important in the history of the high-speed
tric generating, the introduction of Mr. Porter's en-
ng-mill work was of even greater moment. The early
deliberate because man was habituated to slow move-
irst power came from the slow-turning water-wheel,
slow-speed steam engine. Faster movements were
gh gears and belts and then came the direct-connected,
ed high-speed engine.

At the first Annual Meeting of the Society in 1880, Mr. Porter read a brief paper upon The Strength of Machine Tools,[1] and he subsequently presented numerous others. At the beginning of the manufacture of the Richards indicator, he prepared for the makers, Elliott Brothers of London, a brief treatise on the Steam Engine Indicator, and in 1874 this was revised and very much enlarged by him and brought out simultaneously in London and New York. This contained the tables of the properties of saturated steam which so long remained a standard, based upon the experiments of M. Regnault. Not long before his death he published his Engineering Reminiscences, which are an interesting and valuable account of many incidents in the development of steam engineering. Mr. Porter was a member of the Board of Judges at the Centennial Exposition of 1876.

ILTYD ISAAC REDWOOD

Iltyd Isaac Redwood was born in London, December 16, 1863. He was educated at private schools, attending courses in elementary mechanics and drawing, afterwards supplementing them by evening study.

He began his career as a chemist in 1879 when for two years he acted as assistant to his father, Dr. Theophilus Redwood of the Pharmaceutical Association of Great Britain. In 1882 he became assistant chemist in the laboratory of Young's Paraffin Light and Mineral Oil Company, Ltd., in Scotland, and in 1887 entered the employ of the Queen's County works of the Standard Oil Company at Blissville, Long Island, where he became successively chemist, foreman of various departments, assistant superintendent in charge of construction work, and draftsman. Since 1897 he had been technical manager and expert adviser of the English works of Borax Consolidated, Ltd., manufacturers of borax and allied products

Mr. Redwood was a member of the Society of Chemical Industry, the Royal Society of Arts, and the Aëronautical Society of Great Britain. He entered this Society as an associate in 1890 and was made a full member in 1903. He was the author of several works, namely, Ammonia Refrigeration; Mineral Oils and their By-Products; Lubricants, Oils and Greases; and was a recognized authority in chemical engineering.

[1] Trans. Am.Soc.M.E., vol. 1, p. 119.

STILLMAN W. ROBINSON

ams Robinson died October 31, 1910, at his home
. He was born near South Reading, Vt., March 6,
d the money to defray the expenses of his early
o prepare himself for college as an apprentice to
achinist. In 1860 he entered the University of
ing his way to Ann Arbor mostly on foot and
nses on the way by working as a machinist. From
aduated in 1863 with the degree of C.E., having
lf throughout the college course by skilled instrument
there inventing a machine for graduating ther-
vhich work he was particularly interested. After
ntered the government service as assistant engineer
States Lake Survey, remaining until 1866 when he
alma mater as an instructor in engineering. In 1870
essor of mechanical engineering and physics in the
ial University, now the University of Illinois, estab-
department of mechanical engineering in this country;
as made dean of the College of Engineering. In the
as called to Ohio State University as professor of phy-
anical engineering and occupied that chair until 1895
ed in order to devote his time to his extensive profes-
.

binson was the author of a number of important books
sented before various societies. He also secured about
many of which were fundamental and of great value.
were based upon scientific research and mathematical
nd were the results of skilful study. When the Ohio
first discovered, the problem of measuring the volume
erred to Professor Robinson and solved by him in his
ation of the Pitot tube, resulting in methods now in

in education was always great and led him in 1890 to
sociation composed of teachers of mechanical engineer-
893 developed into the present Society for the Promo-
ering Education. His interest in the University of
ease with his retirement and he made at various times
ions to the equipment of its department of mechanical
ally establishing the Robinson fellowship in engineer-
anent foundation.

The following minute was adopted by the faculty of the Ohio State University, at its meeting following the death of Professor Robinson:

As a man, Professor Robinson was an indefatigable worker. There was no limit to his enthusiasm and ambition in his profession. Personally, he was modest and retiring, never claiming credit for himself though most generous in according it to his associates. He was greatly interested in the work of those around him, impressing his own enthusiasm upon the efforts of both colleagues and students, encouraging, stimulating and rewarding them. His memory and influence will long be felt in the lives of those who follow him and who have taken up his work.

PERCY A. SANGUINETTI

Percy A. Sanguinetti was born in Kingston, Jamaica, B. W. I., June 17, 1844, and died at his home in Mt. Vernon, N. Y., on January 30, 1910.

At the age of sixteen, he entered service as an apprentice in the locomotive shops of his native town. A few years later he received an appointment to the British Navy Yards at Chatham, England, where he worked through the various departments. During this time he passed a successful examination as teacher of mechanical drawing in the evening mechanical schools at South Kensington, London. In 1867, he was appointed by the Admiralty Board to represent the town of Chatham at the Paris Exposition and to report upon its mechanical features.

His experience in the United States dates from the Centennial Exhibition at Philadelphia in 1876, where he served as assistant to the machinery bureau, designing the system of shafting and the cascade in the pump annex and assisting in the experiments with turbines. At the close of the Exhibition he entered the service of the Franklin Sugar Refinery in Philadelphia, where he remained twelve years, conducting during part of this time a course in mechanical engineering at Franklin Institute. In 1893 he acted as mechanical aid at the World's Columbian Exposition in Chicago and for the following three years occupied the chair of mechanical engineering at the Armour Institute of Technology. In 1895 he came to New York to engage in consulting practice and during the two years previous to his death had served in the appraisal bureau of the Public Service Commission.

In 1901, Mr. Sanguinetti secured the coöperation of a score of

anufacturers of this country in the introduction of ery into Jamaica, especially in sugar plantation and nt. His latest work was the remodeling of a sugar w Orleans, which he completed just two months

THOMAS H. SAVERY

very was born in Philadelphia, Pa., on May 31, 1837, me in Wilmington, Del., April 5, 1910. He was edu- ttown Boarding School and later at Friends' Select hia. When sixteen years of age he was appren- ist to William Sellers and Company of Philadelphia, e remained for five years, becoming at the comple- f service general foreman of the Columbus machine mbus, Piqua and Indianapolis Railroad, and later toona shops of the Pennsylvania Railroad. In Jan- cepted a position as superintendent of Pusey and f Wilmington, Del., was admitted as a partner, and th the company as vice-president and then as presi- tirement in 1907 from active service. Mr. Savery sted in the development of paper machinery and it fforts and inventions that the Pusey and Jones Com- acknowledged leaders in building paper machinery. his death he was president of the Harpers Ferry the Shenandoah Pulp Company and the Harpers ght and Power Company, Wilmington, Del. He or in numerous companies in Wilmington, Philadel- ties.

HORACE SEE

esident of the Society in 1888, died in New York r 14, 1909.

Philadelphia, and after the usual classical and mathe- of the private school entered the shops of I. P. ny. Thence passing to Neafie & Levy, and the nd Shipbuilding Company, at Camden, N. J., and f Pottsville, Pa., he entered on his best known life- m Cramp & Sons, Philadelphia.

be designer and superintending engineer in 1879, nd machinery of greatly improved construction and oducing improved methods of work and standards in

that great establishment, and giving to the United States a ship-building plant of capacity and quality compare favorably with the products of the Clyde and Newcastle. It was under his leadership that the United States Navy contracts for the first vessels of what was then called the "New Navy of the United States" were taken, and the big ships of the American Line at that day bore his impress. It was at the zenith of this busy period, when he was confessedly the leader in his field, that the presidency of the Society was placed in his hands. He presided at the Nashville and Scranton meetings of 1888.

The following year it became apparent that avenues of professional advancement would not open further for him in Philadelphia, so that he came to New York with the honors thick upon him won from his busy years. He became at once consulting engineer for the Newport News Shipbuilding and Dry Dock Company, Newport News, Va., and was the host of the Society on his visit to that plant at the Richmond meeting of 1890. He was superintending engineer for the Southern Pacific Company and the Pacific Mail Steam Ship Company, and superintendent for the Cromwell Steam Ship Company, and in his private practice as a marine engineer and naval architect he designed and prepared specifications for many yachts and commercial vessels. Some of his improvements in hull and machinery are in international use.

Mr. See was adjutant of the Twentieth Regiment of the National Guard of Pennsylvania during the riots of 1877, and later Captain of the First Pennsylvania Regiment. Besides various business and social connections, he was a member of the Society of Naval Architects and Marine Engineers, of the Institution of Naval Architects of Great Britain, as well as of the Northeast Coast Institute of Engineers and Shipbuilders, and the American Geographical Society; associate member of the American Society of Naval Engineers and the United States Naval Institute; and fellow of the American Association for the Advancement of Science.

He contributed a paper on the method he introduced for producing true crankshafts for multiple-cylinder engines[1], and his presidential address was a discussion of manual training and methods of instruction for technical work[2].

[1] Trans. Am. Soc. M. E., vol. 7, p. 521.
[2] Trans. Am. Soc. M.E., vol. 10, p. 482.

OLIVER S. SHANTZ

z was born at Breslau, Ontario, Can., August 12,
l his early education at the Berlin and Ithaca high
879 to 1886 he was apprenticed to J. Y. Shantz
Ontario, manufacturers of automatic machinery.
ıtz was graduated from Sibley College, Cornell Uni-
egree of M.E. and six years later received a master's
nical engineering from the same university. He
engaged as engineer and designer for Schaeffer
New York City, for one year; as instructor in
neering at Cornell University for four years; as
e Otis Elevator Company, New York City; sales-
nkin Boiler Company, New York, and assistant
e Edison Portland Cement Company, of Orange,
Mr. Shantz affiliated himself with the Rand Drill
w York, representing them in Chicago, and while
ny made a specialty of sand pumping, installing
ts of this character. In 1905 the Rand Company
) the Ingersoll-Rand Company of New York and
charge of their interests in Detroit. Four years later
employ of J. Y. Shantz and Son Company, Buffalo,
turers of buttons, in the capacity of assistant

d on September 7, 1910, after an illness of a few days.
er of the Manufacturers' Club and the Chamber
uffalo.

GARDINER C. SIMS

ns, president of the William A. Harris Steam Engine
t his home in Providence, R. I., on March 20, 1910.
rn in Niagara Falls, N. Y., July 31, 1845, and was
the public schools. He began his engineering career
s' apprenticeship at the locomotive works of the N.
R. Co., West Albany, N. Y., afterward entering the
ooklyn, N. Y., but returning to his former employers
, to become their chief draftsman. He next became
f the J. C. Hoadley Engine Works at Lawrence, Mass.
rdon Armington, with whom he formed a partner-
ufacture of steam engines, both men devoting their
erimental work as a result of which they gave to the

world the quick-running engine, in opposition to the established engineering practice and precedents. They built the first successful engine for Thomas A. Edison, which was sent to the Paris Exposition with his first dynamo, in 1881.

In 1876 Mr. Sims spent eight months at the Centennial Exposition and was appointed democratic commissioner from the State of Rhode Island to the World's Columbian Exposition in 1892, where he was made chairman of the Exposition committee on electricity and electric and pneumatic appliances, and was a member of the committee on machinery and transportation.

At the outbreak of the war with Spain, Mr. Sims volunteered, and was appointed Chief Engineer by the Navy Department and ordered to the navy yard at Boston. For his work in this branch of the service Mr. Sims was made a lieutenant-commander and received congratulatory letters from Secretary Long and Engineer-in-Chief George W. Melville.

At the close of the war he was summoned by the War Department to assume the position of superintending engineer of the United States Army Transport Service, and discharged his duties with honor until the completion of the work. He was appointed police commissioner in 1902, and at the time of his death was connected with the William A. Harris Steam Engine Company of Providence, R. I.

J. HENRY SIRICH, JR.

J. Henry Sirich, Jr., died January 22, 1910, at Bethlehem, Pa. He was born at Baltimore, Md., April 9, 1881, and received his technical education at the Baltimore Polytechnic Institute, from which he was graduated in the class of 1898. He served his apprenticeship at and afterwards entered the drafting room of the engineering works of Robert Poole & Son Company, now the Poole Engineering & Machine Company, of Baltimore.

In April 1903 Mr. Sirich became an assistant engineer on the steamships of the Atlantic Transport Line, remaining with them a year during which he secured a United States license as second assistant engineer of ocean condensing steamers of 10,000 gross tons. From 1904 to 1908 he was connected with the American Bridge Company at Ambridge, Pa., and the Westinghouse Machine Company, East Pittsburg, Pa. In the latter company he entered first the turbine-testing department, of which he became foreman in September 1905, and later was transferred to the turbine-erecting department of the New York district, as trouble foreman.

e became connected with the power department of eel Company and held the position of chief drafts- f his death.

WILLIAM W. SNOW

ow who died at his home in Hillburn, N. Y., April n at Heath, Franklin County, Mass., July 17, 1828. of age he took up the book-binding trade, but in ecome assistant civil engineer with the Worcester ilroad. In 1848 he went to Woonsocket, R. I., succeeding years was employed in the foundry at ı he accepted a position as superintendent of the y Foundry. In 1856 he established a factory at ., for the manufacture of car wheels. This business carried on under the general management of Mr. , when he withdrew his interests to become general Union Car Wheel Works, Jersey City, N. J. In came to Ramapo, N. Y., and with others organized ıeel and Foundry Company, of which he was made and superintendent and finally president. In 1881 e Ramapo Iron Works in Hillburn, N. Y., a village ıelf. Nine years later he began the erection of com- gs in Mahwah and installed therein the Ramapo Company. He was the president of this company lation with the American Brake Shoe and Foundry he became chairman of its Executive Board, which at the time of his death.

Snow was appointed by Governor Morton one of the commissioners to the Atlanta, Ga., Exposition. He ty in 1889 and was also a member of clubs in Boston, d Chicago. He was well known in European circles ost prominent manufacturers of this country.

ERNEST PACKARD SPARROW

rd Sparrow, who died in Dorchester, Mass., on April born at Portland, Me., September 17, 1857, and rly education from the Westbrook Seminary. In duated from the Worcester Polytechnic Institute with S.

Mr. Sparrow's first shop experience was with the Indurated Fibre Company, Gorham, Mass. He was subsequently associated with the Fitchburg Steam Engine, the Mather Electric Light, the Thompson-Houston Electric Light, the Jarvis Engineering, the E. P. Allis, the Boston Rubber Shoe, and the New Brunswick Rubber companies. For the past few years he had been associated with the B. F. Sturtevant Company of Hyde Park, Mass., where he was engaged on special engineering work.

Mr. Sparrow was affiliated with several benevolent orders and organizations.

ALBERT SPIES

On August 16, 1910, Albert Spies, editor and proprietor of Foundry News, died suddenly at his home, 40 Glenwood Avenue, Jersey City, N. J. He was born in New York City, July 20, 1862, and received his early education from tutors and at the Hoboken Academy. When only nineteen years old he was graduated from Stevens Institute of Technology, and for a number of years engaged in engineering practice and technical journalism. In 1893 he became editor of Cassier's Magazine, and in 1904 also assumed the editorial conduct of the Electrical Age. For several months he brought out both papers practically unaided until the pressure of work forced him to relinquish his activities on the latter journal in January 1906. In the fall of 1906, following the death of Louis Cassier, Mr. Spies severed his connection with both papers and in February 1907 became editor of the Electrical Record, continuing until early in 1910 when he resigned to bring out his own paper, Foundry News. Only four issues were published prior to his death.

Mr. Spies was a member of the Engineers Club and the American Institute of Mining Engineers, as well as an associate member of the American Institute of Electrical Engineers.

SAMUEL EVANS STOKES

Samuel Evans Stokes, the son of Dr. John H. Stokes, was born at Moorestown, N. J., on October 3, 1846, and died at his home in Germantown, Philadelphia, on November 12, 1910. He was graduated from the Lawrenceville school in 1863 and immediately went into the machine works of Isaac P. Morris and Company in Philadelphia. Here he remained for four years, going from one department to another and becoming an expert machinist and draftsman. After two years spent in large works in Detroit he formed a partnership

h, known as the Stokes and Parish Machine Works.
obtained the concession for all the machinery re-
entennial Commission and the exhibitors and were
ge of Machinery Hall and the erecting of exhibits,
team elevator which ran from the main hall to the
terward the firm began to build hydraulic elevators
me their specialty.
ous nervous breakdown made it necessary for Mr.
from active business, and the firm was taken over
rator Company of New York. In 1896 Mr. Stokes
th his family, remaining in Europe for two years.

CHARLES SWINSCOE

coe, consulting engineer of the Clinton Wire Cloth
on, Mass., was born at Nottingham, England, Jan-
His early education was received in the Collegiate
ter, England. He came to this country when a lad
was Fourth Officer on the Dreadnought under Capt.

1854 Mr. Swinscoe studied practical mechanics in
. In 1867 he established the steam pump works of
ake Manufacturing Company, at Boston, designing
k. In 1876 he left this company to take charge of
draulic Works, designing its steam pumping ma-
1878 to 1880 he was in charge of the Bay State
and after that date of the Clinton Wire Cloth
on, Mass., of which in 1903 he became consulting
ied at Clinton, Mass., November 5, 1909.
was a musician of ability and was president of the
Union and organist of the Episcopal Church for many
a member of the Clinton Historical Society, and
ty in 1887.

ROBERT BARNARD TALCOTT

rd Talcott was born at Richmond, Va., December 1,
ted at the public and private schools of that city
ton, D. C., later receiving instruction in mechanical
vening courses of the Linthicum Institute, George-

s business career by entering the office of W. H.
pany, merchant millers, Washington, D. C. In 1882

he became draftsman for the E. D. Dent Company, and ... for the supervising architect of the United States Treasury. From October 1906 to February 1909 he was general manager of the Vacuum Cleaner Company of New York City. With the exception of this period, Mr. Talcott, remained in the heating and ventilating division of the supervising architect's office of the United States Treasury until October 1910, when he was furloughed on account of his health. He was at various times assistant chief engineer in this office, consulting mechanical engineer of the Department of Agriculture in Washington and consulting mechanical engineer in connection with the power plant for the United States Soldiers' Home, Washington, and the Walter Reed United States Army Hospital, Washington. He died December 4, 1910, at Lutherville, Md.

Mr. Talcott became a member of this Society in 1907. He was also a member of the American Society of Heating and Ventilating Engineers and the American Society of Inspectors of Plumbing and Sanitary Engineers.

FREDERICK MERIAM WHEELER

Frederick Meriam Wheeler of Montclair, N. J., died at his summer home in Westhampton, Long Island, on September 15, 1910.

Mr. Wheeler, who was born in Brooklyn, N. Y., in 1848, was graduated from Summit Academy in New Jersey, and subsequently attended the Polytechnic Institute, Brooklyn, N. Y. His early apprenticeship was served in the machine shop of the Lake Mills, Lake Village, N. Y., and he later studied mechanical engineering for five years under Henry J. Davison of New York City. He made hydraulic and marine engineering his specialty and for over thirty-four years was associated with the George F. Blake Manufacturing Company, of New York, of which he became director and secretary. When the company was absorbed by the International Steam Pump Company, together with other hydraulic works, Mr. Wheeler was made a director in the new company.

Mr. Wheeler was the inventor of the Wheeler surface condenser which is extensively used in this country and Europe and has been adopted by the United States Navy. He organized the Wheeler Condenser and Engineering Company, with wo... at Carteret, N. J., and was also officially connected with the Ludlow Valve Manufacturing Company of Troy, N. Y.

Mr. Wheeler was a charter member of the Society of Naval

Marine Engineers, and was also a member of the
y of Naval Engineers and of the Engineers Club of
served as a member of the advisory council of the
ıgress at the Columbian Exposition in 1892, and had
been prominent in public and social circles in his
was one of the charter members of the Society.

ALFRED WILKINSON

ıson, who died at his home in Bridgeport, Pa., on
), was born at Stockport, in Cheshire, England, May
he attended the common schools and the Mechanics
ıen fourteen years of age he came to the United
the Richmond shops of the Philadelphia and Reading
any where he remained till 1862. When the Civil
t he enlisted in the navy and served under Admiral
g promoted for meritorious service to third assistant
the close of the war he entered the employ of Carr,
)evlin, Philadelphia. In 1876 he opened an office of
ıdelphia as expert steam engineer, and in 1891 invented
mechanical stoker which today bears his name and
ively used on ocean liners and in large manufacturing
e same year Mr. Wilkinson organized the Wilkinson
Company at Bridgeport, Pa., and began the manu-
nvention. He was at the time of his death president
y.

ɔn was a member of the Franklin Institute and the
Club of Philadelphia. He inherited his mechanical
father, Joseph Wilkinson, who invented a cook stove
tic oil cup for steam engines.

CHARLES HENRY WILLCOX

ry Willcox died at his home in Westport, Conn., on
1909. Mr. Willcox was born in Little Falls, N. Y.,
839, and was the son of James Willcox, founder and
e Willcox & Gibbs Sewing Machine Company. He
ıer's business at the age of eighteen and was contin-
ed with the company as mechanical engineer from
retirement a few years before his death and most of
irector. The natural bent of his mind was toward
in collaboration with James E. A. Gibbs he developed

and placed on the market the invention of the single-thread chain-stitch sewing machine, which is now so widely used in the making of wearing apparel. Other patents followed, in particular that of the automatic tension, which it is said consumed ten years of patient experimentation before it was perfected. Mr. Willcox was also the inventor of two straw-hat sewing machines, in one of which the stitch is visible and in the other the stitch concealed. These two machines are used to-day in the manufacture of fully 90 per cent of all straw hats made. The knit goods manufacturing field also received an impetus through the invention of the Willcox & Gibbs hosiery trimming machine. The overlock machine worked out by Mr. Willcox in collaboration with the late Stockton Borton, was a great advance over the hosiery trimming machine and is recognized as one of the finest mechanical productions in sewing machines. Through the ornamental character of its stitch it has been adopted in lines of manufacture other than that for which it was originally intended.

In addition to his connection with the Willcox & Gibbs Sewing Machine Company, Mr. Willcox was for forty years affiliated with the Brown & Sharpe Manufacturing Company, Providence, R. I.

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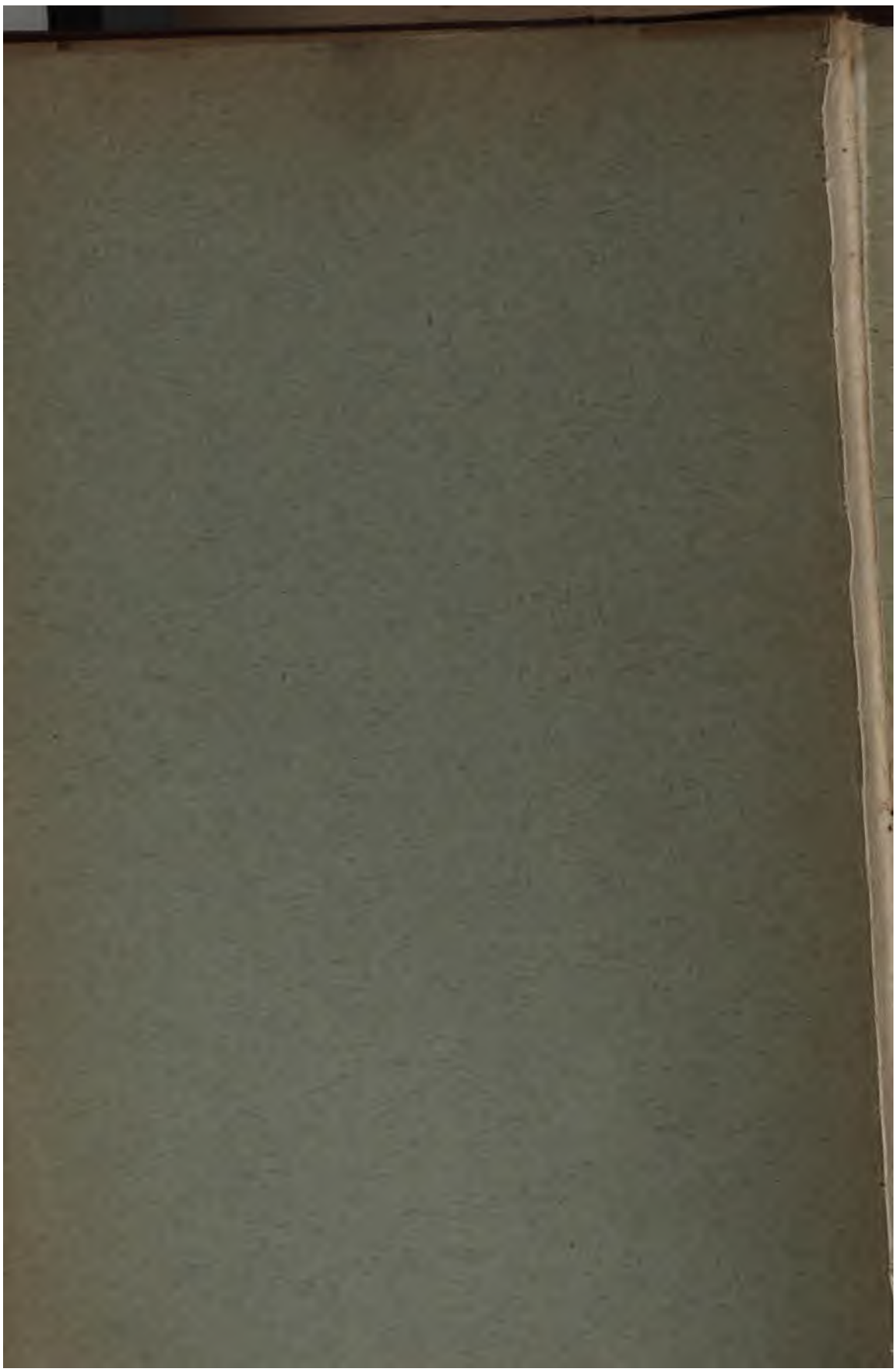

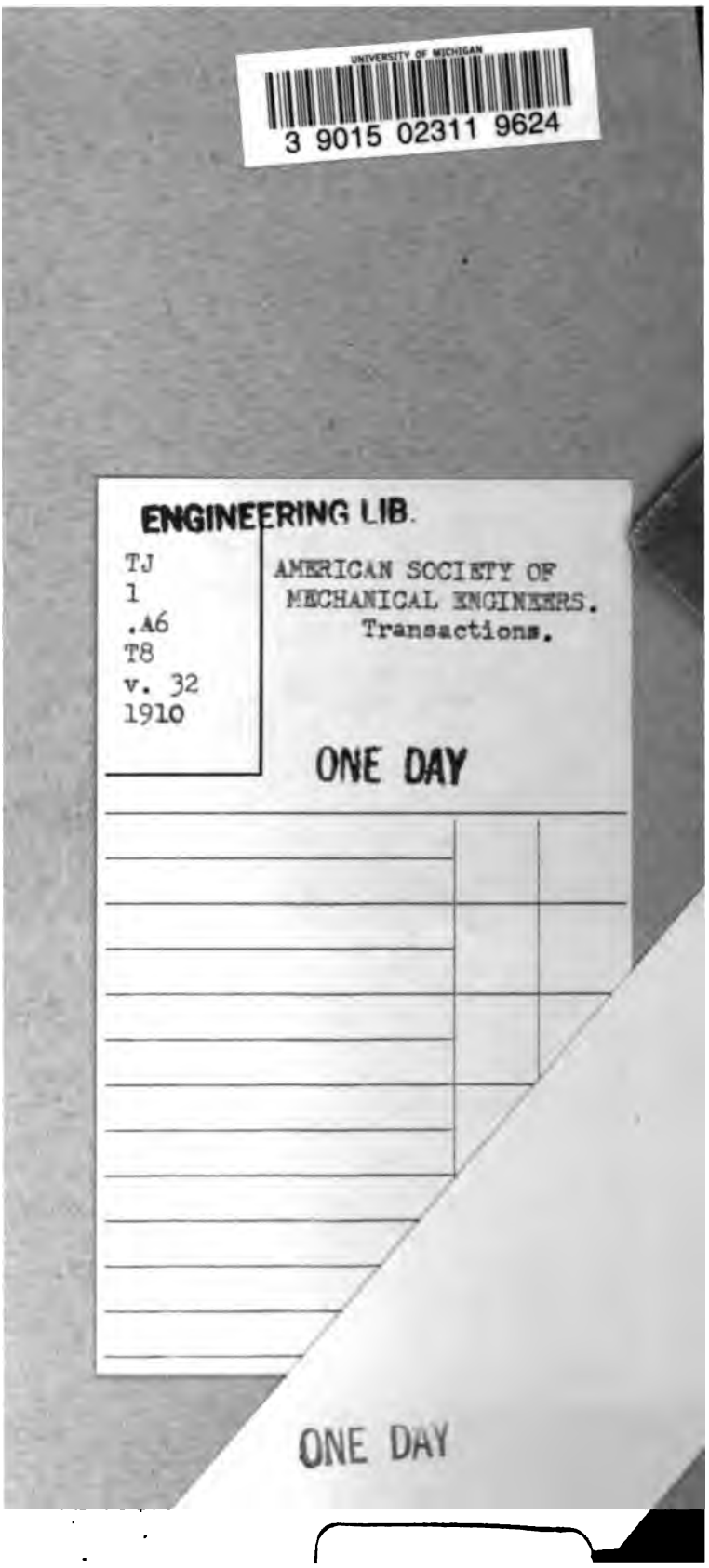
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